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NEW LOOK

ISSUE 131
JULY 2022

ALL ABOUT SPACE

FROM THE BIG BANG TO ITS ULTIMATE FATE
ARE WE ALONE IN THE COSMOS?
YOUR QUESTIONS ANSWERED

THE UNIVERSE EXPLAINED

EXCLUSIVE: NASA'S CHRIS FERGUSON

"I REALLY DIDN'T KNOW WHAT TO EXPECT"

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WELCOME

ISSUE 131

If you've ever wanted to know everything there is to know about the universe, you've come to the right place. This issue, we explain everything from its birth to its ultimate fate – and what's going on in between. Over the years we've discovered that you, our readers, have burning questions about the cosmos, and we've answered the most popular in our cover feature. If yours didn't make the list, then why not ask us via our contact details below?

There's plenty to keep you entertained this month – from our mysteries of the universe feature covering whether we're closer to cracking a complex 2,000-year-old mystery in the Antikythera mechanism to the secrets that the Large Hadron Collider could uncover about the cosmos.

For the skywatchers among you, we've got a full guide on how best to observe the planets and over ten pages on the best night sky sights this month, whether you have binoculars, a telescope or are just using the unaided eye. Enjoy the issue, and I'll see you next time!

GEMMA LAVENDER
Content Director

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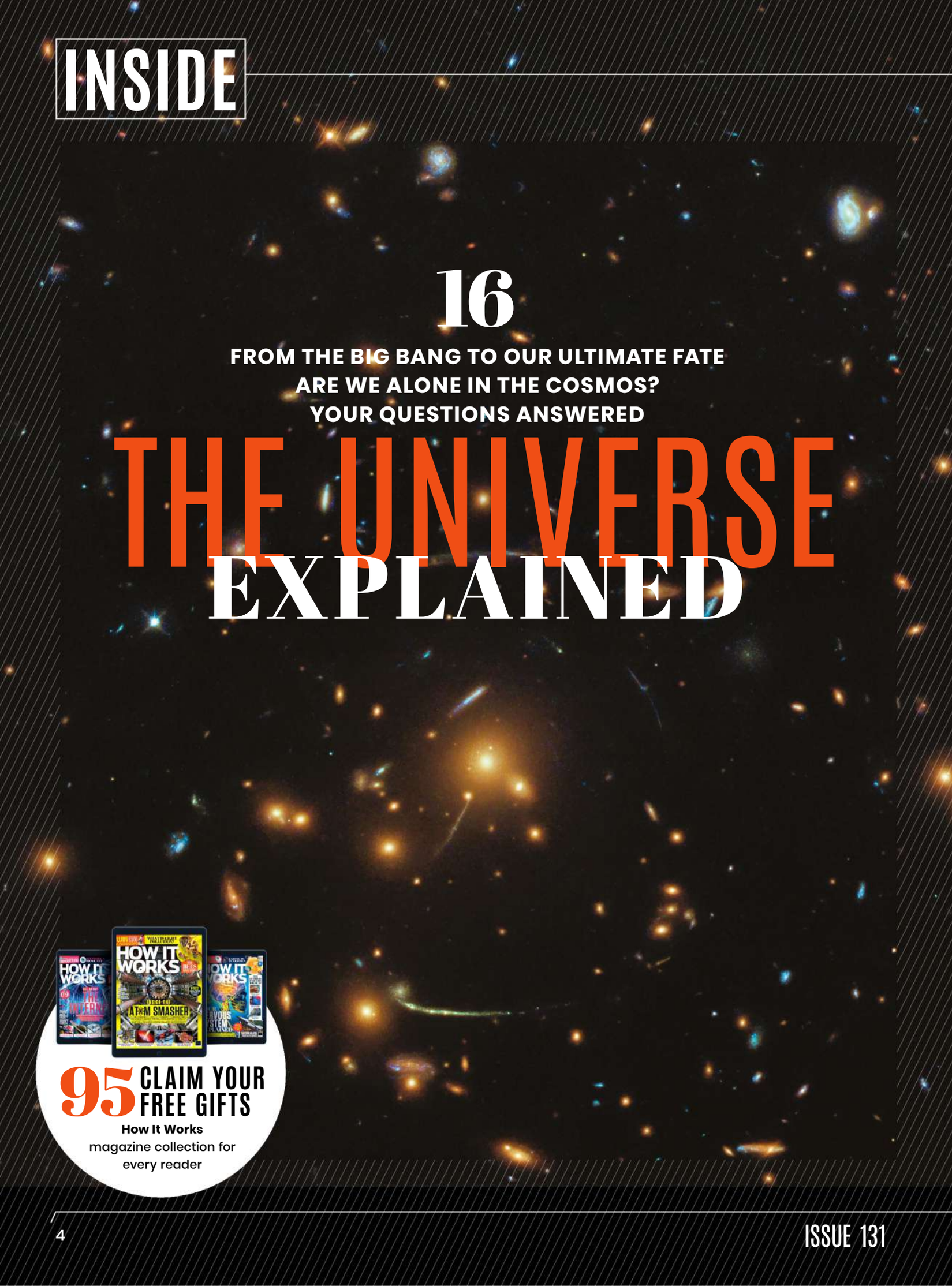

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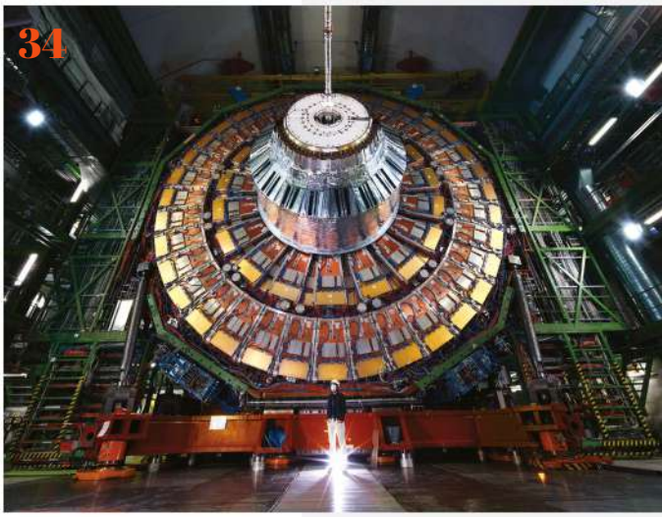

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28 April 2022

Martian stretch marks

Scratches and grooves on the Martian surface look like a huge fingernail was gouging out regolith on the Red Planet, but there's a volcanic origin to these features. Scientists believe that these faults, dubbed Tantalus Fossae, were created by the volcano Alba Mons, which is located to the west of the terrain visible in the striking new views. The images are based on data gathered by the European Space Agency's (ESA) Mars Express mission, which has been orbiting Mars since 2003.

These intriguing gouges around the flanks of Alba Mons are known as grabens, which formed as the mountain grew. As volcanic activity pulled at the Martian surface, parallel fault lines opened up circling the peak; the rock between them dropped into the empty space this created, like geologic stretch marks. The grabens stretch in an incomplete ring around Alba Mons for a total length of 1,000 kilometres (620 miles). In some places, the grabens are as deep as 350 metres (1,150 feet) – more than three times the height of the Statue of Liberty.

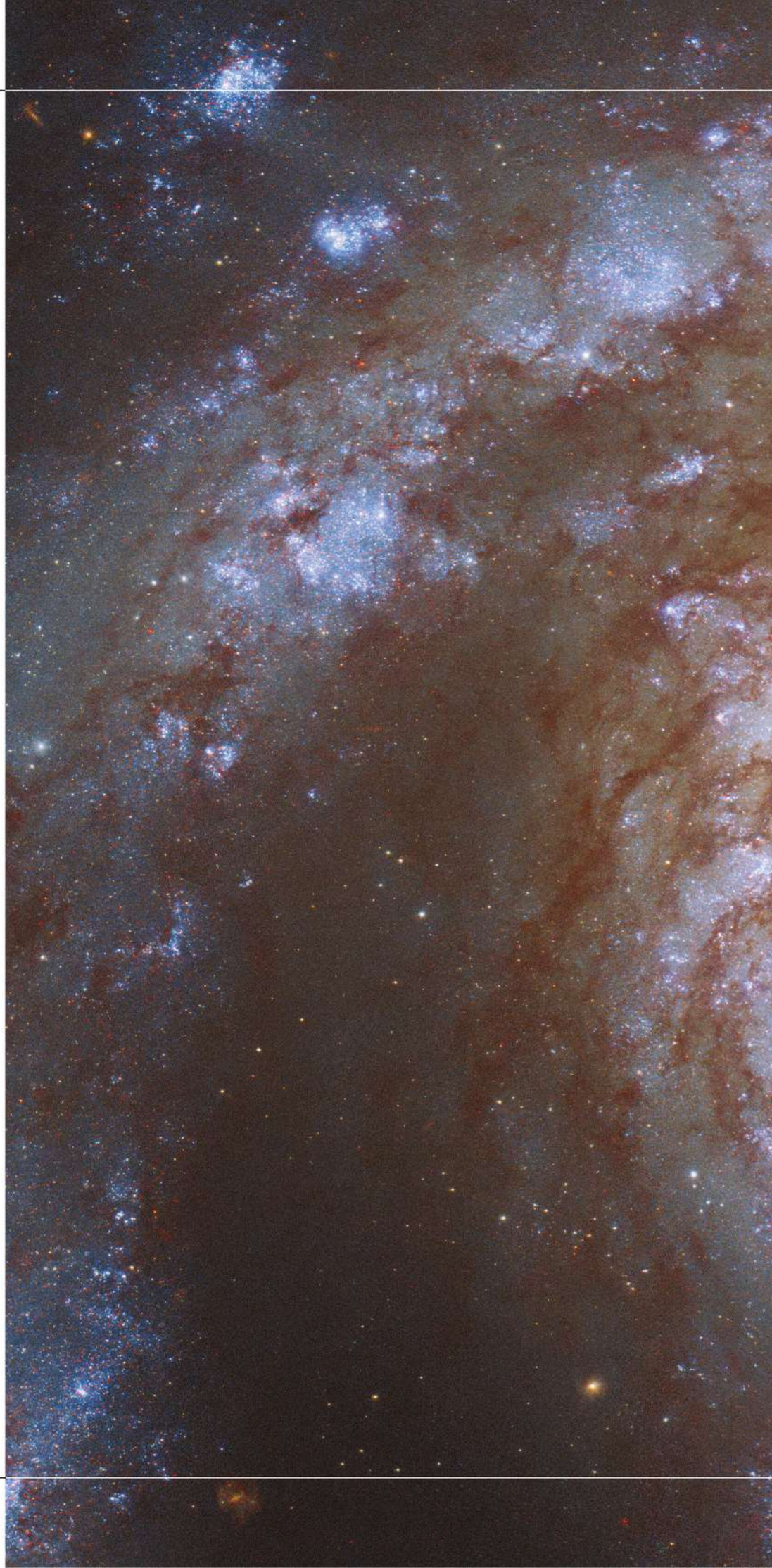
© ESA

2 May 2022

Hubble's grand design

A newly released image from the Hubble Space Telescope shows the mesmerising spiral of Messier 99. Particularly on display are the galaxy's well-defined stellar arms, branching from the dusty, yellow centre of the galaxy. The glittering strands of Messier 99 are located 42 million light years away from Earth. Separate observations allowed Hubble's Wide Field Camera 3 (WFC3) to capture a sharper view of the prominent, star-embellished arms of the spiral galaxy. The image displays a stark contrast between the radiant purple-blue hues of the extending star-dense regions and dark surrounding space.

Messier 99, like the Milky Way, is a grand design galaxy, meaning that it has particularly pronounced spiral arms. This category includes about ten per cent of all spiral galaxies. The Hubble image was a result of two separate studies on the galaxy. The first research focused on stellar explosions called novae. These explosions, which ensue from white dwarf stars pulling matter from a larger star, are much less violent than supernovae, which mark the deaths of massive stars. However, astronomers also believe that there's an intermediate type of explosion brighter than a nova but fainter than a supernova. Previous observations of Messier 99 conducted in 2010 at the Palomar Transient Facility discovered an object in the spiral galaxy with this type of in-between brightness.



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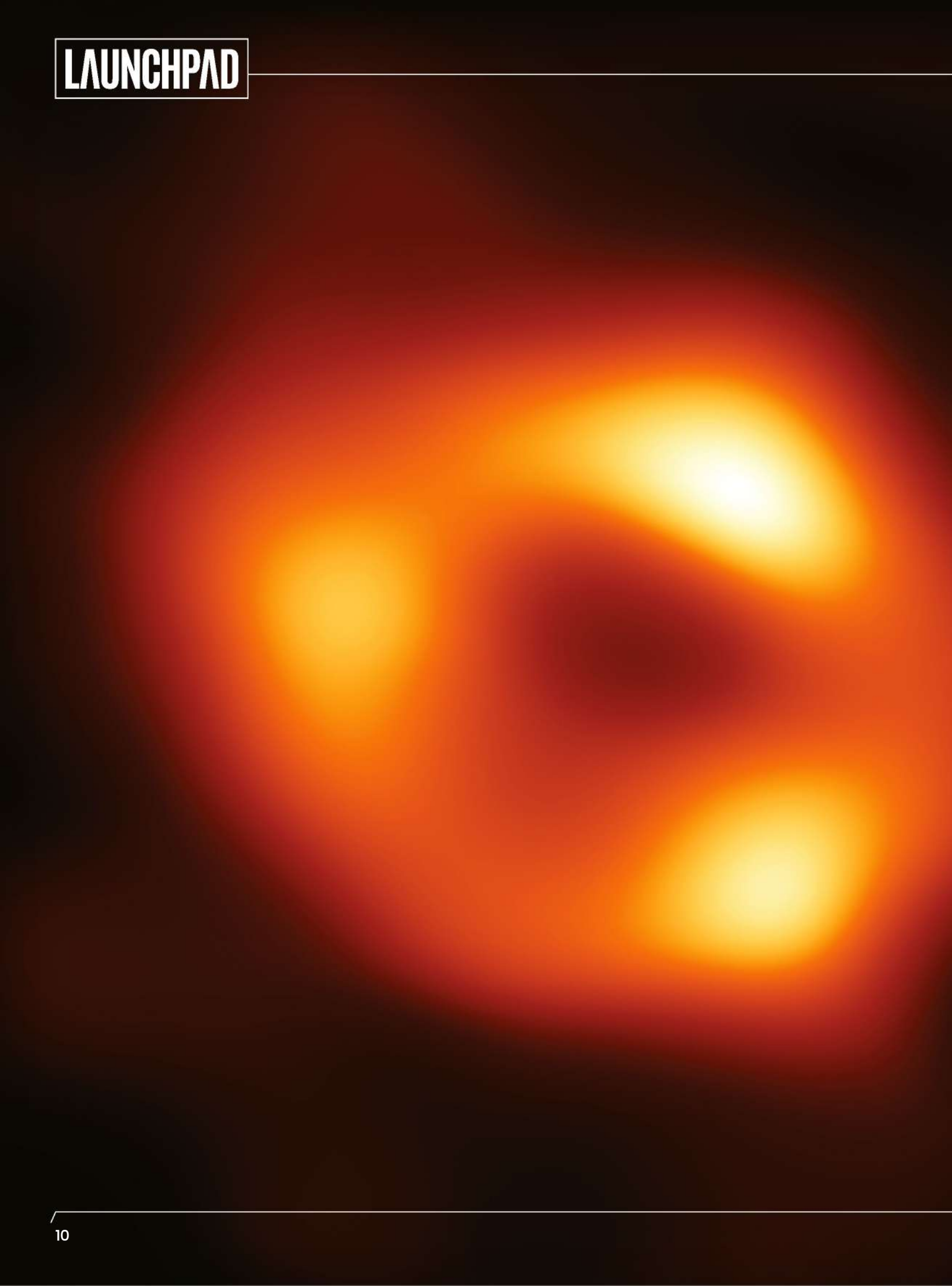
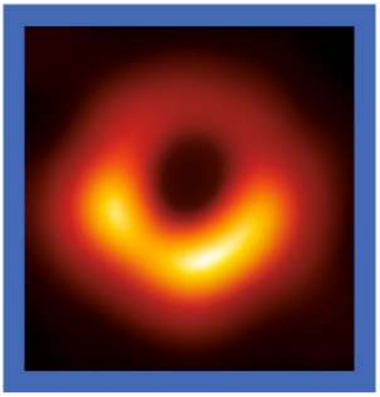




12 May 2022

First image of our galaxy's black hole

The Event Horizon Telescope has captured a historic first image of the supermassive black hole at the centre of our galaxy. The image, which was taken in the light of submillimetre radio waves, confirms that there's a black hole at the heart of the Milky Way that's feeding on a trickle of hydrogen gas.

"Until now, we didn't have the direct picture to prove that this gentle giant in the centre of our galaxy is a black hole," Feryal Özel, an astrophysicist at the University of Arizona, said. "It shows a bright ring surrounding the darkness and the telltale sign of the shadow of the black hole."

This is an astounding achievement," Ryan Hickox, an astrophysicist at Dartmouth College who is not a member of the Event Horizon Telescope team, said. "I think I speak for a large number of my astronomy colleagues when I say how remarkably grateful we are." In 2019, the Event Horizon Telescope made headlines when it succeeded in producing the first-ever image of the event horizon of a black hole, specifically the black hole at the centre of the active elliptical galaxy Messier 87 (above).

© ESO

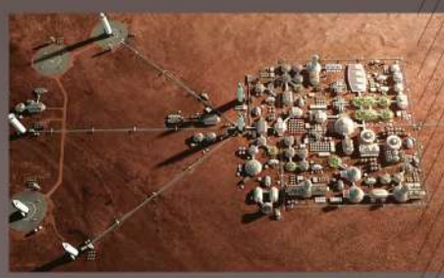
Humanity will go to Mars 'in this decade', SpaceX president predicts

Reported by Mike Wall

A crewed Mars mission could happen sooner than you think. Astronauts will likely make it to the Red Planet's surface before the end of the 2020s, SpaceX president and chief operating officer Gwynne Shotwell said recently. "I think it will be in this decade, yes. People on the Moon sooner," Shotwell said. "I think we need to get a large delivery to the surface of Mars, and then people will start thinking harder about it," she added. "Then I think within five or six years, people will see that that will be a real place to go."

SpaceX aims to be the one to make this ambitious vision a reality. The company is developing a huge, reusable rocket-spaceship combo called Starship to take people and payloads to the Moon, Mars and beyond. Starship already has several Moon missions on its docket. In 2018, for example, Japanese billionaire Yusaku Maezawa booked the vehicle for an around-the-Moon trip with a target launch date of 2023. And NASA picked Starship to be the first crewed lunar lander for its Artemis program, which plans to put astronauts down near the Moon's south pole in 2025 – including the first woman and person of colour.

NASA views Artemis as a Moon-to-Mars program and intends to launch a crewed Red Planet mission in 2040 or thereabouts — about a decade later than Shotwell sees boots first crunching into the red dirt. SpaceX is working towards a big milestone in Starship's development — the vehicle's first-ever orbital test flight, which the company wants to launch from its South Texas facility, called Starbase, in the near future. That launch cannot happen, however, until the US Federal Aviation Administration (FAA) wraps up an environmental assessment of the activities at Starbase.



SpaceX artist's concept of a city on Mars

Artist's depiction of a supermassive black hole before flaring up

Black hole might have executed a magnetic 'flip'

Reported by Elizabeth Howell

A black hole may have reversed its magnetic field right before our eyes. A galaxy known as 1ES 1927+654 briefly ceased X-ray emissions for a few months, then resumed and increased. So far the potential black hole observations represent a unique situation visible from 236 million light years away. If scientists can confirm that the outburst was due to a supermassive black hole at the heart of the galaxy changing its magnetic field, the event may help astrophysicists understand how such a switch affects the black hole's environment.

The Milky Way and most other large galaxies like it have a supermassive black hole embedded at their heart; the black hole pulls matter in towards its centre. The matter first collects in an accretion disc surrounding the black hole, then heats up and emits light as the matter is pushed inward. As that matter pushes inward, it forms a cloud of extremely hot particles that scientists call a corona. A new study suggests that changes in the corona are what caused the X-rays streaming from the heart of 1ES 1927+654 to temporarily disappear.

If a magnetic reversal took place, causing the north pole to become the south pole, and vice versa, visible and ultraviolet light should increase towards the centre of the galaxy due to more heating as the corona begins to diminish and the accretion disc grows more compact in the centre. But as the flip evolves, the field weakens so much that the corona cannot be supported at all any more, causing the X-ray emissions to cease. That idea matches observations of this galaxy, as X-ray emissions re-emerged in October 2018, roughly four months after they disappeared, suggesting a magnetic reversal took place.

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The World View space capsule ascending into Earth's stratosphere in an artist rendering of the technology

Start-up sells 1,000 tickets for balloon trips near the edge of space

Reported by Tereza Pultarova

A space balloon start-up which plans to fly paying customers to the edge of space as early as 2024 has signed up its 1,000th customer, making it the most sought-after space tourism operator in the world. The Arizona-based World View sells rides on its space balloons for $50,000 per seat, about one-ninth the price of a spaceflight ticket with Virgin Galactic. Relying on helium-filled balloons, World View won't deliver the full space tourism experience with weightlessness, but its customers will see planet Earth from 23 miles (37 kilometres) above, almost three times higher than the cruising altitude of a passenger jet. At this altitude, you can observe the curvature of Earth as well as the star-studded blackness of the sky. The experience is more of a slow-burn six to eight hours compared to the adrenalin-filled rocket-powered flights offered by Virgin Galactic or Blue Origin.

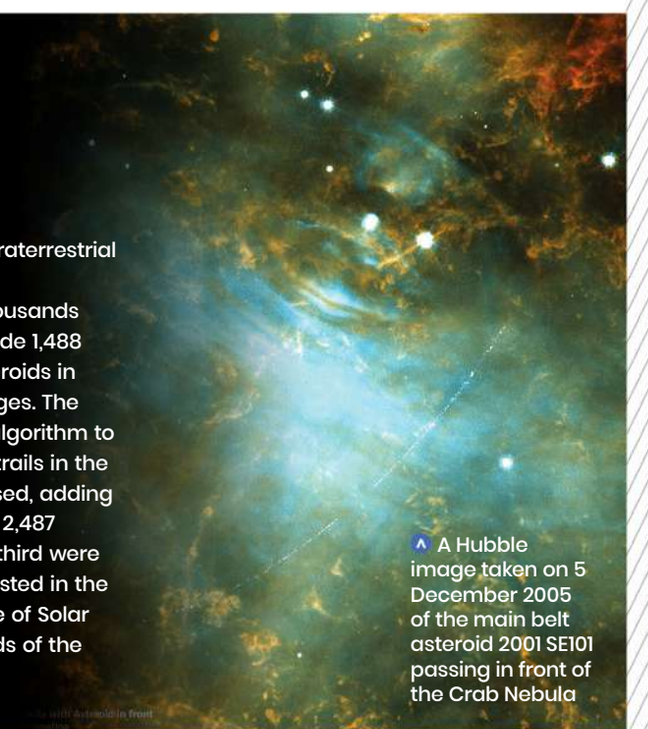
To increase the allure, World View plans to launch its flights from some of the world's most spectacular locations, including the Grand Canyon, Great Barrier Reef and the pyramids of Egypt. Flights from the Grand Canyon spaceport have already sold out for the first year of operations. "Reaching 1,000 reservations underscores the passion, excitement and interest for this unique experience that World View offers," World View CEO and president Ryan Hartman said. "The fact that the Grand Canyon spaceport flight has sold out for the first year also showcases the market demand and growing interest in space tourism."

Asteroid treasure trove found in old Hubble data

Reported by Chelsea Gohd

In a new study, astronomers and amateur scientists have worked together to comb through archival data from Hubble. The project's aim was to identify asteroids in old data – signals that might have been filtered out as noise in other studies. Because the typical observation time for these instruments is 30 minutes, the team knew that moving asteroids would appear in the images as streaks. But such streaks can be tricky for automated computer systems to detect, making the team's efforts uniquely valuable. "It's difficult to tell a computer how to automatically detect them," said Sandor Kruk, a researcher at the Max Planck Institute for Extraterrestrial Physics in Munich.

11,482 volunteers perused thousands of images for streaks. They made 1,488 tentative identifications of asteroids in about one per cent of the images. The astronomers then trained an algorithm to search for additional asteroid trails in the data that may have been missed, adding about 900 detections, totalling 2,487 possible asteroids. About one-third were identified as known asteroids listed in the Minor Planet Center's database of Solar System objects, while two-thirds of the trails remain unidentified.



A Hubble image taken on 5 December 2005 of the main belt asteroid 2001 SE101 passing in front of the Crab Nebula

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THE UNIVERSE EXPLAINED

Meet the people behind the experiments searching for answers to how our universe began

Reported by Giles Sparrow

The universe almost seems to have come out of nowhere. A concoction of high temperatures and a thick gloop of exotic particles that would go into an overdrive of expansion through several phases of varying conditions to create the universe as we see it today some 13.8 billion years later: the Big Bang, creator of time and space – or at least that's what our current understanding of how our universe sprang into existence leads us to believe.

But what we have come to learn about the cosmos' somewhat mysterious past wasn't always as tacked down, going back to the days of Georges Lemaître, who would later be dubbed the father of the Big Bang theory. What the Belgian priest, astronomer and professor of physics did suspect back in 1927, based on his solutions to Albert Einstein's equations, was that the universe must have sparked into life from a single point at the beginning of time before driving headlong into an expansion.

"The evolution of the world can be compared to a display of fireworks that has just ended; some few red wisps, ashes and smoke," Lemaître said of how we were thrown into existence. "Standing on a cooled cinder, we see the slow fading of the suns and we try to recall the vanishing brilliance of the origin of the worlds."

However, Lemaître wasn't recognised as the genius he was until later; he published his work in an obscure Belgian scientific journal where few scientists saw it. As such, his chance to go down in history was lost. Instead, an American astronomer was gathering data that would strongly support Lemaître's theory. Edwin Hubble and his assistant Milton Humason were busy at the eyepiece of a telescope at Mount Wilson Observatory in California, surveying so-called spiral nebulae. These used to be thought of as part of our Milky Way, but Hubble showed that they were island universes in their own right – galaxies like our own millions of light years away. He did this by measuring their redshift. This is just like the pitch of a police siren racing past you. As the police car speeds towards you, the Doppler effect causes the sound waves to bunch up, making the pitch go up. As the police car moves away the sound waves become more stretched and the pitch of the

YOUR QUESTIONS ANSWERED

IS SPACE FLAT OR CURVED?

On a local scale, the fabric of space-time is warped around every object that has mass in the universe thanks to gravity. The shape of the universe overall, though, is different. Given our observations using the likes of WMAP, which measured fluctuations in the universe's radiation, we think that it's fairly flat. Just like on a local scale, the mass of the universe has an influence on the overall geometry of the cosmos. Knowing its density of matter and energy tells us whether it's open like a saddle shape, closed like a sphere and flat like a sheet of paper. With an idea of its shape, we can work out the universe's fate. In the case of a flat universe, it's predicted that it will expand forever.

JACK BRANSON

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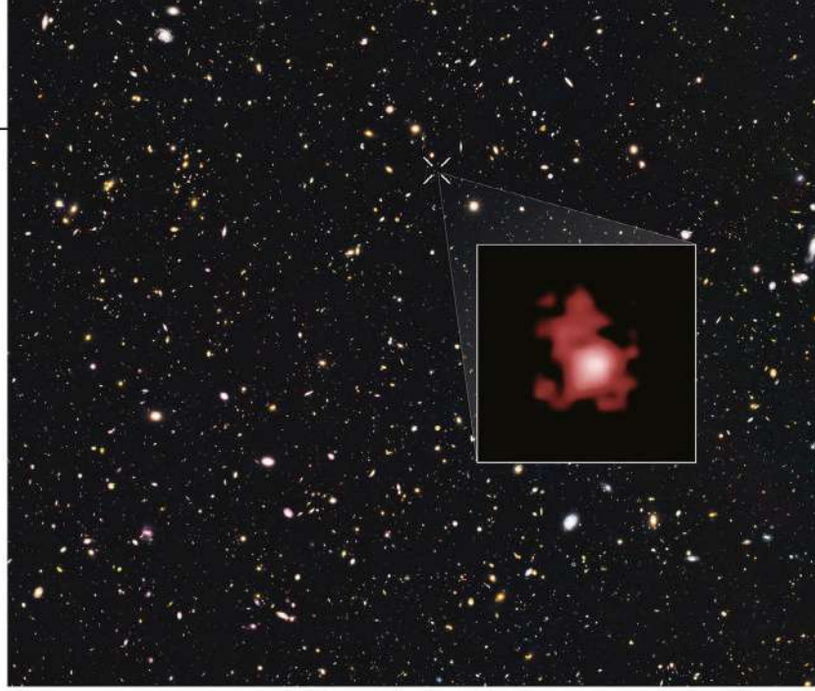


GN-z11 is one of the most distant galaxies detected, with light leaving it 13.4 billion years ago

siren falls. In space, objects moving towards us have the wavelength of their light rays compressed into bluer wavelengths, which astronomers term blueshift, while objects moving away have their light stretched into redder wavelengths, hence redshift. Hubble found that almost all the galaxies had redshift, meaning they were all moving away from us according to what became known as Hubble's law. But if the galaxies are all moving apart, could they once have been much closer together?

In 1931 Lemaître's work was brought to people's attention when Arthur Eddington discovered it, but by then Hubble had already made his discoveries. At first Einstein didn't believe it, but later changed his mind when he saw Hubble's evidence. A more vocal critic was astronomer Fred Hoyle at Cambridge University, who came up with the name 'Big Bang' in derision of the idea, favouring his own steady-state model which described an eternal universe. The Big Bang name stuck, however.

Today the Big Bang is a widely accepted theory. However, we don't have a photo album of how the universe grew up from an infant, transforming into the veteran of cosmic evolution it is today. Astronomers realised that they had to be resourceful, grabbing hold of any tantalising evidence that our universe was willing to give and combining them with mathematical models. Of course, these clues are communicated to us in the cosmos' own way, ranging from the crackling of its background noise – the cosmic microwave background (CMB) – to gravitational waves that ripple between its many galaxies.

And telling us things about its past the universe is certainly doing. The CMB is not exactly the stealthiest of beasts – it generated interference in the experiments of Bell Laboratory astronomers Arno Penzias and Robert Wilson in 1965. While using a sky-scanning device called the Holmdel Horn Antenna in New Jersey – a radio telescope that listened in on the universe – everywhere they pointed their telescope, they detected an unwanted hiss, kind of like

SEEING THE START

And then there was light. That's pretty much how our universe sprang into existence – as a point that contained everything and continued to expand through to today, building the first stars and galaxies and stretching light years of distance between them. Despite its name, the Big Bang wasn't some kind of explosion that spat out matter, energy, time and space. It's imagined like a balloon that continues to stretch, originally holding an incredibly hot and dense primordial soup that cooled and thinned out over millions to billions of years.

Such an event has opened up a whole deluge of questions. And the only way to attempt to look back in time is to lift missions off the ground to seek answers. Several missions have stepped up to the challenge, most notably the Planck mission – which communicated its final signal in October 2013 – under the joint efforts of the ESA and NASA. Planck built upon and improved observations returned by NASA's Wilkinson Microwave Anisotropy Probe (WMAP), which after a good nine years of service rests in its heliocentric graveyard orbit. Planck's main aim was to measure the CMB – the afterglow of the Big Bang that's encoded with how the universe appeared some 400,000 years after the event. To get the best measurements possible, the mission had to be kept at freezing temperatures, with "a passive cooling and three refrigerators taking it to -273.05 degrees Celsius [-460 degree Fahrenheit], which made it the coolest place in the universe," says the University of Manchester's Richard Davis, who led the UK's involvement in one of the instruments on board the craft. "It also had the lowest noise detectors ever made."

An important feature of the CMB is that it's by no means smooth. It's a mess of different temperatures, and it was from soaking up this relic radiation from its orbit around the Sun that Planck was able to pick out even the most subtle blips in temperature – something the mission did incredibly well. "The fluctuations go down to as low as two microkelvin," Davis tells us. "Planck surpassed its expectations and in some cases even exceeded its goals, so it has been stunning."

Indeed, a couple of the many achievements that the space mission has in its arsenal are an all-sky survey that has provided us with one of our best views of the oldest light in our universe as well as a better measurement of the age of the cosmos, dated at 13.8 billion years old – 100 million years more than previously thought. And even though the mission has since been deactivated for almost a decade now, Davis assures us that Planck could still wield the key to understanding more about our infant cosmos while its data continues to be investigated for new discoveries.

the low level of electrical noise that produces static on a television screen. They even thought the interference could be caused by bird droppings in the horn. Only after they had ruled out every possible alternative did they finally accept that the unexplained signal could be coming from space. What's more, it was coming from all directions.

They soon realised that it was the sought-after background radiation that scientists suspected might exist. If our universe had a beginning then there was likely to be some kind of residue left over. And at a temperature just a few degrees above absolute zero – about -270 degrees Celsius or -454 degrees Fahrenheit – it's actually quite cold, making today's universe quite a chilly place to be, as this radiation fills every corner of space. Once it was quite hot, but has cooled as the universe has expanded.

The CMB was emitted 380,000 years after the Big Bang, when temperatures in the universe fell to below about 3,000 degrees Celsius (5,432 degrees Fahrenheit). At this temperature, atomic nuclei were able to soak up all the free electrons that whizzed around the universe. With these electrons out of the way, light and radiation were allowed to freely pass through space without bouncing off electrons – this is the light we see now as the CMB. Although it doesn't quite show us the moment of the Big Bang, the appearance of the CMB is heavily influenced by what happened in the Big Bang, such as a

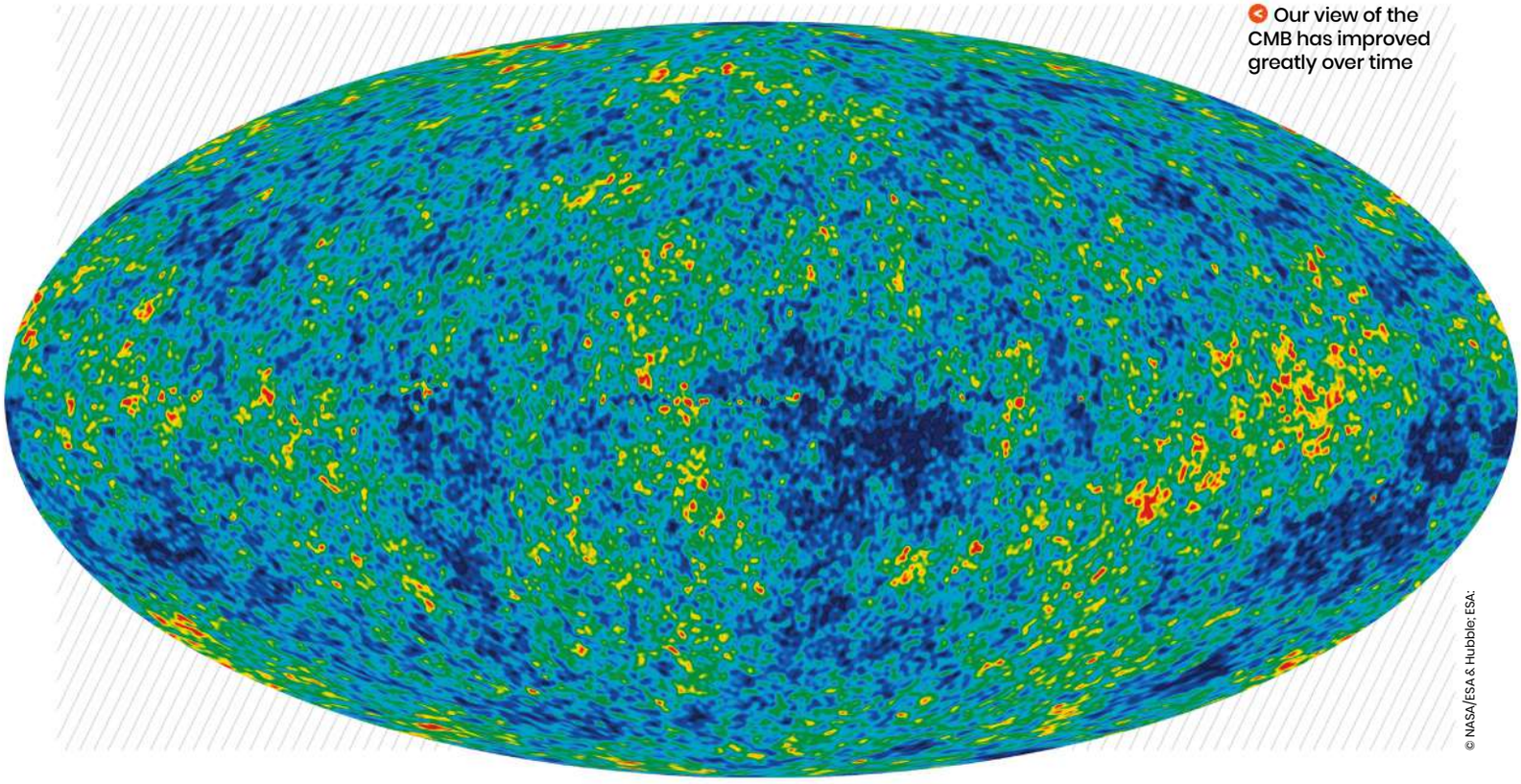
"If our universe had a beginning, there was likely to be some kind of residue"

YOUR QUESTIONS ANSWERED

HOW DO WE KNOW THAT THE UNIVERSE IS A 'COSMIC LATTE' COLOUR?

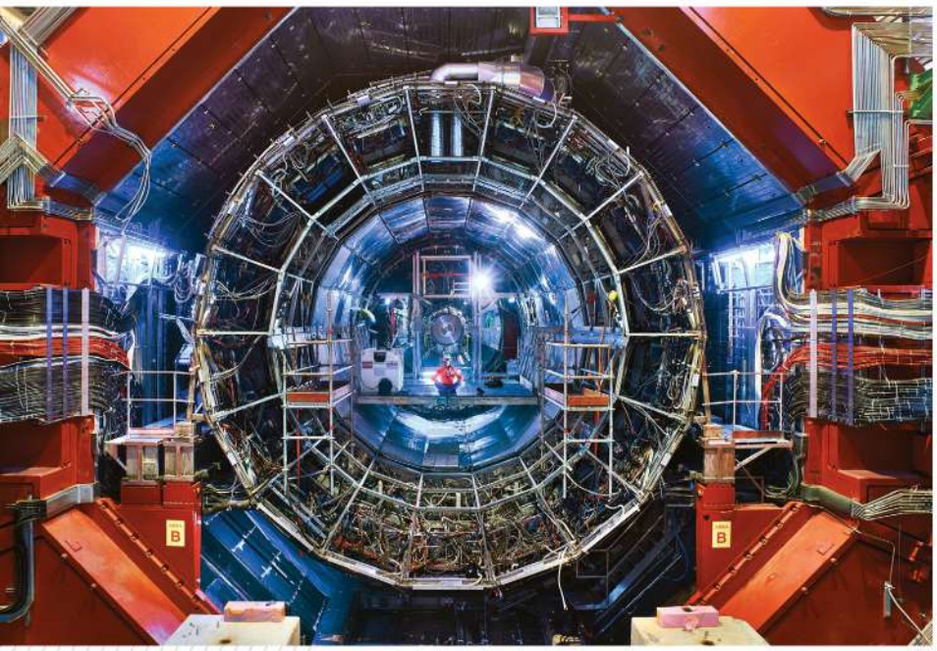
When we go outside and look at the night sky, it looks black in between the stars. But that's because we cannot see the millions of faint galaxies that are spread throughout the universe – our eyes cannot detect enough of this light. Instead we can use a telescope and analyse the light from millions of galaxies, spreading out each galaxy's light into a spectrum, like a rainbow. If we then average the light from these galaxies, we can create a digital spectrum that represents the light emitted in our universe. Comparing this cosmic spectrum with the spectrum of a white light, the universe's colour is beige, or as one of our readers called it, cosmic latte. This idea was taken further by Katie Paterson's studio in the UK. For their art project, I calculated the colour of the universe over time from the Big Bang and even estimated what it would be like in the far future. From this, the art studio created a colour wheel called the 'Cosmic Spectrum'. The universe started out extremely hot, with a blue colour, cooling to orange as the universe expanded. And then the first stars formed in young galaxies, becoming blue again. Now it's the beige-yellow colour, and in the far, far future, trillions of years from now, it will be red again as most of the light could be from red dwarf stars.

HANNAH DRURY



Our view of the CMB has improved greatly over time

© NASA/ESA & Hubble; ESA;



ALICE is an experiment at the Large Hadron Collider at CERN. Colliding lead nuclei, the resulting smash is thought to be enough to produce a quark soup

brief period of inflation that moved parts of the universe apart faster than the speed of light. The picture that the CMB provides is one of the baby universe – it's almost like we're looking back to when time and space first shuddered into existence.

Penzias and Wilson were awarded the Nobel Prize for their discovery, but there was still much to learn about the CMB – we wanted a map. Stepping up to the challenge, a fleet of missions have since come and gone, the very first being the NASA-owned Cosmic Background Explorer (COBE) probe, which began snapping pictures of the CMB as soon as it was launched in 1989. Offering four years of service,

"It's almost like we're looking back to when time and space first shuddered into existence"

COBE produced the very first map of hot and cold spots within the CMB, brought about by the early universe's gravitational field that would later form the seeds of gigantic clusters of galaxies that stretch for hundreds of millions of light years across the universe. COBE's lead scientist, George Smoot, also won the Nobel Prize, but hot on the heels of COBE came the Wilkinson Microwave Anisotropy Probe (WMAP). It boasted an improved resolution and got to work mapping the entire sky, logging the differences in temperature of the CMB down to 25 millionths of a degree.

What WMAP also uncovered told astronomers about the shape of the universe; they figured that since the boldest and brightest bursts in the map were a mere one degree across, we must be living in a flat universe. By 2010 WMAP had sniffed out its last microwave, producing over nine years of information. WMAP had laid down some important foundations, making the mission a huge breakthrough. Meanwhile, as WMAP was put into retirement, a new space observatory was waiting in the wings, ready and willing to build on our knowledge

RECREATING THE BIG BANG

At the European Organization for Nuclear Research (CERN), the particle-smashing Large Hadron Collider (LHC) has been hard at work accelerating particles to breakneck speeds close to the speed of light. The aim? To attempt to recreate what the early universe might have been like just a few minutes after it was born. The accelerator, which houses two detectors dedicated to pinpointing moments during our universe's growth, works as a Big Bang-making machine. But this 'explosion' is on a much smaller scale and scientists have a bit more control over it.

For A Large Ion Collider Experiment (ALICE), the aim is to smash particles of lead into each other to create a plasma that existed some ten-millionths of a second after the Big Bang. The plasma produced in ALICE is fairly representative of the gloop of the early universe. But the fireball created is much smaller and hence will cool much quicker. The results brought about by the detector are indicative of breakthroughs in our understanding of the early cosmos.

Meanwhile, LHC beauty is trying to solve the reason behind why there were unequal amounts of antimatter and matter after the Big Bang.

OBSERVING THE AFTERMATH

Around 13.8 billion years later, here we are. As the stars, galaxies, planetary systems and other bodies are silently suspended in an endless void of blackness, it's difficult to believe there was a time in the universe's life where conditions were chaotic and ever-changing. But unable to keep its turbulent past under wraps, there's evidence everywhere and in all directions – the Hubble Deep Field made sure of that.

"The Hubble Deep Field revealed distant galaxies which appear very different from nearby galaxies," explains Dan Coe, an astronomer based at the Space Telescope Science Institute in Maryland. "They are generally smaller, more clumpy and less orderly than nearby galaxies and yet to form spirals or settle into elliptical balls."

Constructed from a series of observations over a period of ten days, this tiny snapshot – which is equivalent in size to a 65-millimetre tennis ball held at a distance of around 100 metres (328 feet) away – holds 3,000 objects, most of which are galaxies. Several of these structures are among the youngest and most distant known – providing a pathway that allows us to look back to when the universe was young. "Distant galaxies appear redder," adds Coe. "This redshift is due to the expansion of the universe. As the universe expanded over billions of years, it stretched light along with it into longer, redder wavelengths. Ultraviolet starlight emitted billions of years ago from distant galaxies has been stretched along its journey to our telescopes to red or even infrared wavelengths."

The advent of a new infrared camera on board Hubble saw astronomers take the opportunity to gauge an even deeper look into the universe's past and reveal ever more distant galaxies with greater redshift. "Even if our eyes were as large as Hubble's, these galaxies would remain invisible to us," says Coe. "We believe the most distant galaxy detected in the Ultra Deep Field dates back to 500 million years after the Big Bang, over 13 billion years ago."

But Coe and his colleagues are looking even further still. "The Hubble Ultra Deep Field was about twice as big as the original," he says. "We embarked on a large Hubble program to observe 12 more Ultra Deep Fields in different parts of the sky."

The program Coe is referring to is a venture called Frontier Fields and can tell us how similar other patches of sky look to the Ultra Deep Field; that way we can confirm that – as suspected – the cosmos is expanding in all directions. Hubble was joined by Spitzer and the Chandra X-ray Observatory to bring us images of the Frontier Fields in the flavours of infrared and X-ray.

Coe reminds us that telescopes that haven't made the trip outside of the atmosphere have surveyed wide areas of the night sky, and while they've found that the universe looks similar in all directions, there's a lot of structure. "Over billions of years, gravity has woven a 'cosmic web' of dark matter that funnels gas in to form stars and galaxies and draws galaxies together to form large clusters of galaxies," the astronomer explains. "The original Hubble Ultra Deep Field may have landed on a dense cosmic knot or a cosmic void in the distant universe. That's why we need more Ultra Deep Fields, to sample more of the distant cosmos."

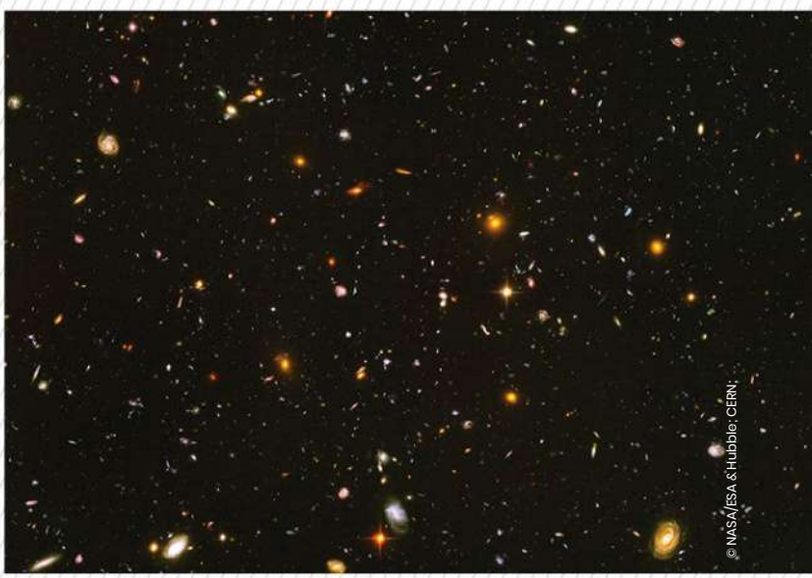
of the early universe thus far – the European Space Agency's (ESA) Planck. Operating in a range of microwave and infrared frequencies, the spacecraft promised an even higher level of accuracy, putting its instruments into overdrive in an attempt to lock down any answers given away by the deepest recesses of the universe. And Planck gave as good as it got from the universe, imaging the CMB in unprecedented detail. It might have ended its mission in October 2013, but we are now the proud owners of a more accurate picture of an almost perfect universe, as well as a more prominent point in time when the event began.

The truth of the matter is that this microwave background isn't the only feature of the universe that's telling us how it began – there's more enticing evidence, and

Coe and his colleague Jennifer Lotz, an associate astronomer at the Space Telescope Science Institute who leads the Frontier Fields program

Coe is part of the Frontier Fields team – a venture to look back in time to the early universe

Hubble's Ultra Deep Field shows hundreds of high-redshift galaxies



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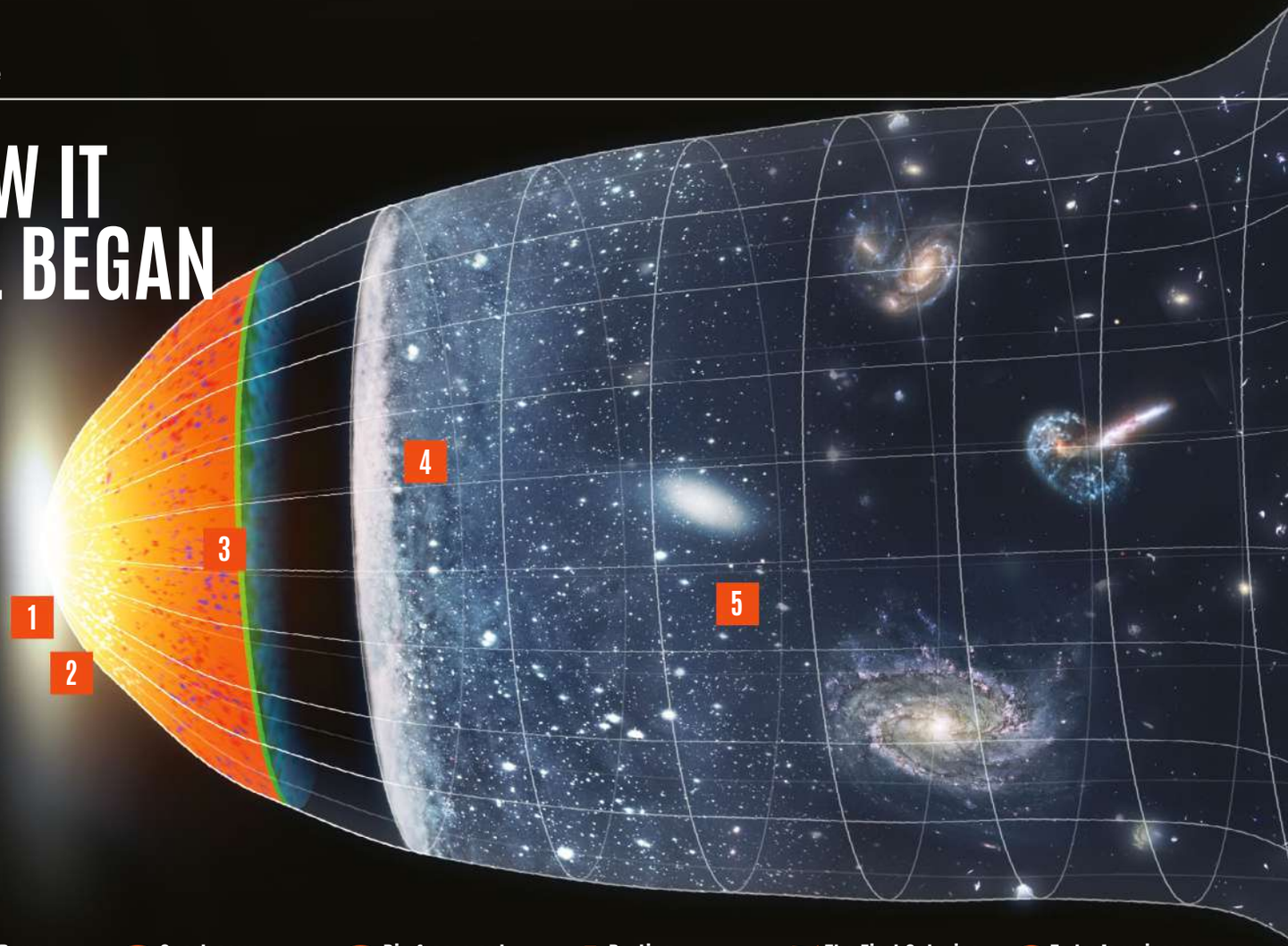
HOW IT ALL BEGAN



1 The Big Bang
The event that is said to have created time and space, according to the now-defunct Planck, is thought to have occurred some 13.8 billion years ago. Here the universe was infinitely hot and dense before cooling and inflating.

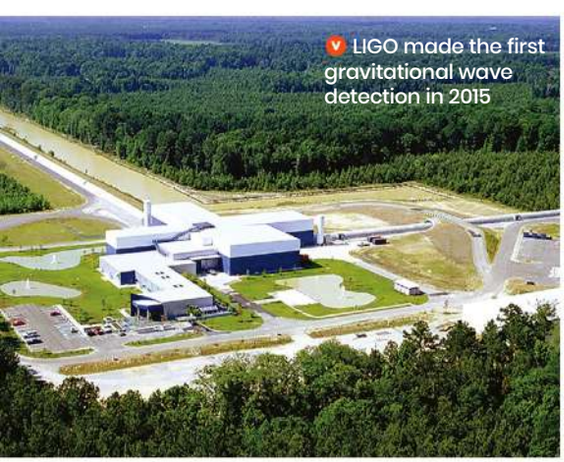
2 Quark soup
One-trillionth of a second after the Big Bang, the weak and electromagnetic forces separated, leaving us with the four major forces we know today – the strong, weak, electromagnetic and gravity.

3 Big freeze out
A hundred seconds after the Big Bang, the temperature dropped to the point where protons and neutrons could stick together without being torn apart. Conditions were ripe for hydrogen to form.

4 Parting company
After some 300,000 years, the opaque soup began to clear. Since the temperature of the universe had dropped, photons were travelling through the universe, free from matter.

5 The First Galaxies
Gravitational attraction between atoms brought them into faint clouds of gas, which pulled in more and more material from their surroundings. Around 1 billion years after the Big Bang, the first stars and galaxies were born.

6 Today's universe
In comparison to the turbulent changes that it went through when growing up, the universe we see today – pinpointed with galaxies, stars and planets, among other structures – is much calmer.



LIGO made the first gravitational wave detection in 2015

we're making sure we're taking advantage of it. These extra telltale signs are ripples in space-time called gravitational waves. These elusive oscillations represent one of the jigsaw pieces of Einstein's theory of relativity. Gravitational waves can be created by all kinds of massive objects, but some were also believed to have formed in the Big Bang and could still be rippling through the universe today. The problem is that it's not easy to directly detect them, but their evasive behaviour means that the universe also has difficulty influencing them under its will. This is good news for us, as they're the only known form of information that's able to reach us undistorted from the instant of the Big Bang. The trick is catching them, because you need very sensitive detectors indeed.

Not put off by their shyness, scientists have been intent on pinning these waves down. Unlike the common electromagnetic radiation that we're used to, gravitational waves, which are the result of massive events such as the merging of supermassive black holes, like to work their way through all types of matter – whether it be gas or dust. Attempts to grab gravitational waves by the tail, which include the likes of a large-scale experiment called the Laser Interferometer

6

"Shortly after its sudden appearance, there was nothing except for a plasma soup"

LISA will be the first dedicated space-based gravitational wave detector

Gravitational-Wave Observatory (LIGO), haven't gone unnoticed, but the events are still quite rare. We need something better, and while 'advanced LIGO' has been in the works since 2008, the ESA has been thinking outside Earth's atmosphere and straight into the thick of space.

The plan is to build a mission that has the ability to deal with such a slippery character. Scientists think they might have that pegged with the help of a planned mission, the Laser Interferometer Space Antenna (LISA) – a large-scale space mission that will not only better detect this phenomenon, but will be able to survey the entire universe directly with these waves, unpacking the secrets locked in the formation of galaxies, how stars evolve as well as the early universe.

And that's not all... planned for launch in 2037, the people behind the craft proudly proclaim that it will also be able to tell us more about the structure and nature of space-time. There will also be the opportunity for uncovering more about black holes, as well as other unknown objects. Before it begins to achieve its incredible goals, an advanced scout, namely LISA Pathfinder, was launched in 2015, paving the way for LISA in an attempt to test the complex art of gravitational-wave detection.

As we understand from the reams of data brought about by the teamwork of missions and theories, we think we've put together a pretty robust photo album – or timeline – from the universe's birth all the way through to its 13.8-billion-year-old self. Shortly after its sudden appearance, there was nothing except for a plasma soup. The universe was incredibly hot, with particles of both matter and antimatter – the opposite of matter – rushing apart in all kinds of directions. Then it began to cool, producing equal amounts of matter and antimatter, which swiftly annihilated each other.

Luckily for us, and for some reason that nobody currently understands, there was extra matter left over. As the universe began to peter out, cooling further, particles – the building blocks of matter – began to take shape. The first stars formed around 400 million years after the Big Bang, followed by the first galaxies – the oldest galaxies we've seen so far are a whopping 13.7 billion years old.

As much as we are sure the Big Bang happened, the universe can still throw a spanner or two in the works by presenting

Missing pieces

Disappearing antimatter

In the beginning, there were equal helpings of matter and antimatter – materials that annihilate one another. If there were equal amounts, why do we live in a universe dominated by matter?

The horizon problem

When we look at the CMB coming from widely separated parts of the sky, we wonder if these regions are so far apart to have ever communicated with one another, even with signals travelling at light speed. If these parts of the sky are unable to communicate, scientists are unsure how they know to have the same temperature.

The flatness problem

Evidence suggests that the present universe is pretty much flat. Experts think its current form is a very unlikely result of the universe's evolution.

Galaxy formation

According to some, the random bumps in the expanding universe aren't quite enough to allow the making of galaxies. In a rapidly expanding universe, gravitational attraction loses the fight and is too slow for these to form.

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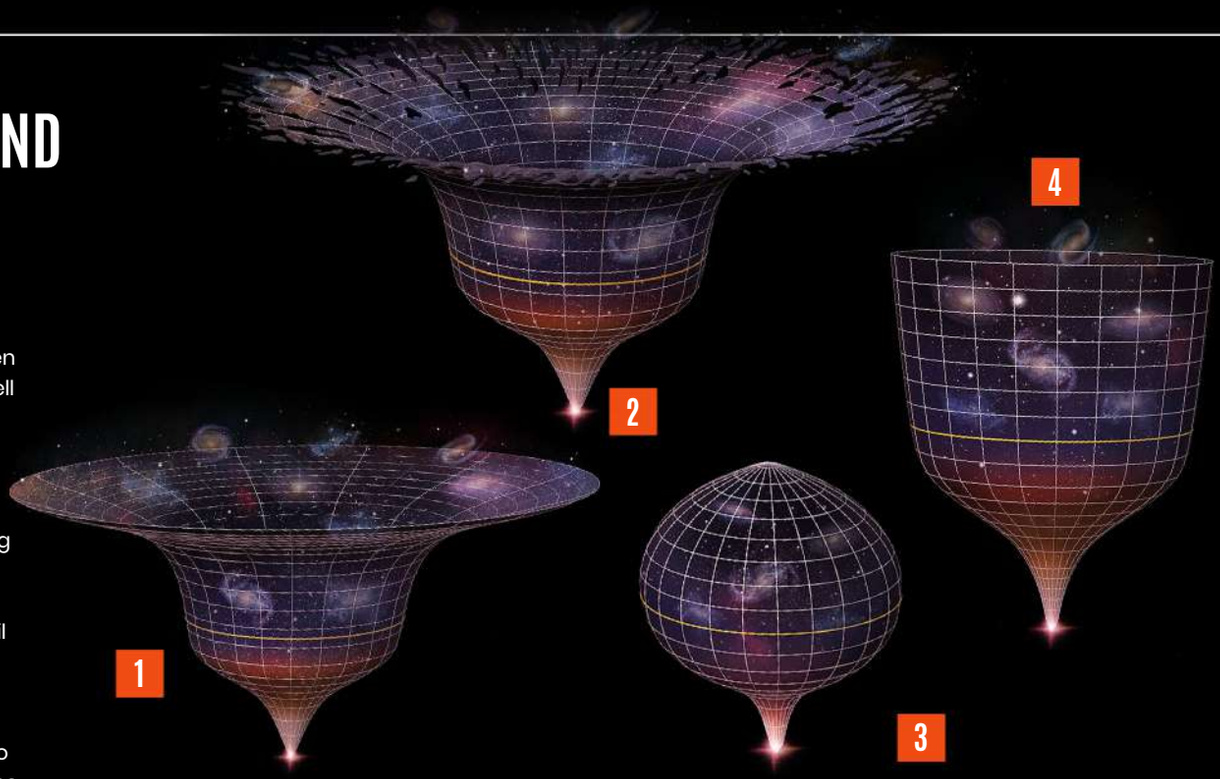
HOW IT WILL END

They say all good things must come to an end – and our universe is no exception. But just how it'll be snuffed out is a subject up for debate and depends on the battle between dark energy and gravity as well as its density. There are three possible fates. One is called the Big Crunch, where gravity takes over and begins to pull the cosmos back, compressing it to one point. Another is the Big Rip, where the expansion of the universe gets faster until galaxies, stars, planets, atoms and space itself are ripped apart. Somewhere between these is what WMAP showed to be the likely scenario, where the expansion of the universe is not great enough for a Big Rip and gravity not strong enough for a Big Crunch. It will continue to expand, carrying everything over the cosmic horizon. Objects will be so far away that their light cannot reach us. The sky will be dark. As all of the stars go out, the universe will grow cold and lifeless in a so-called big freeze.



1 Cosmological constant
Einstein proposed a 'cosmological constant' along with his theory of gravity that could be causing a steady rate of cosmic expansion.

2 The Big Rip
If the rate of expansion due to dark energy continues to accelerate, it's possible that space-time will be slowly torn apart.

3 The Big Crunch
If dark energy ceases to expand the universe, this could cause the universe to collapse in on itself in a scenario opposite to the Big Bang.

4 The Big Slurp
This fate could happen at any time. If the Higgs field, associated with all mass, transitions into a state known as a 'false vacuum', it will cause the cosmos to decay.

a few things that we are still trying to figure out. Where did the universe come from? We don't know. Why did it appear in the first place? We really can't be too sure. And there's more. The fact that there was more matter than antimatter in the early universe along with why a mysterious repulsive form of energy, known as dark energy, is causing the expansion of the universe to accelerate rather than slow down as had been expected are questions leaving scientists scratching their heads. What we do know is that the Big Bang was not an 'explosion' into anything – the Big Bang happened everywhere, which is why everywhere is filled with the CMB. And we also know that the ultimate destiny of the universe depends on who wins the great cosmic battle over the fate of the cosmos. Will gravity tug the universe back or will dark energy keep it expanding forever?

Giles Sparrow
Space science writer
Giles has degrees in astronomy and science communication and has written many books and articles on all aspects of the universe.

YOUR QUESTIONS ANSWERED

WOULD WE NOTICE IF THE UNIVERSE STOPPED EXPANDING?

We would notice that the night sky would be a lot brighter, since the objects within it wouldn't be moving away from us. It was in 1823 that astronomer Heinrich Wilhelm Olbers also wondered what would happen if the universe was infinite and static. He came to the conclusion that the night sky would be brighter since light from an infinite number of stars would reach Earth. Since we know that the cosmos is expanding, we know this isn't the case. If the universe had begun in its present state, we wouldn't be able to see the shifting of light from one end of the light spectrum to the other from distant galaxies, also known as redshift. Over time, it's quite likely that gravity would pull everything in the universe towards each other in a 'Big Crunch'.

STEVEN BENNETT

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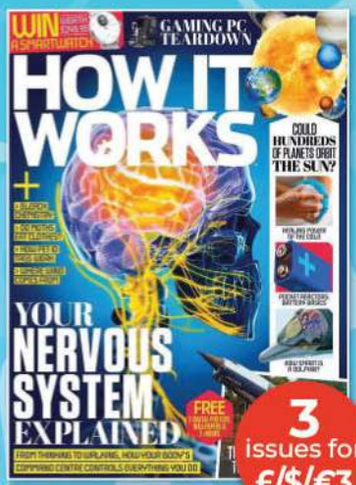

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FUTURE TECH

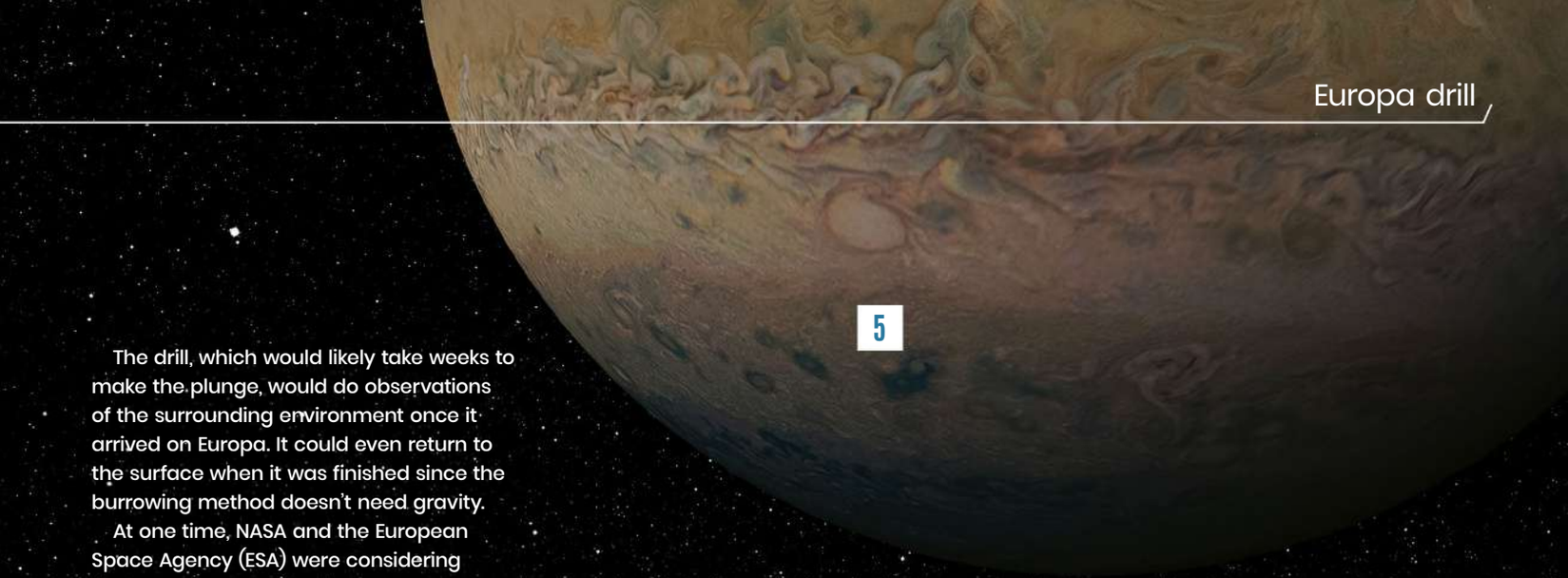
EUROPA DRILL

What lies under the Jovian moon's ice? A mission is needed to probe its secrets

If there's water or some similar liquid under the surface, it's possible that Europa could host life. It would most likely be microbial life – something that's suited to living in cold temperatures. But we can't know for sure without drilling. The 2013 movie *Europa Report* explored this possibility in detail when the crew needed to drill several kilometres into the ice. However, it would take quite a robust drill to make it that far. How best to design it?

A few years ago, representatives from New York City-based Honeybee Robotics proposed the Inchworm Deep Drilling System (IDDS), which could potentially handle the kilometres of ice between the spacecraft and the liquid below. In papers presented as part of a Lunar and Planetary Institute workshop on Europa exploration, the drill was showcased as a way to head deeper than one kilometre (0.62 miles) without the need for a tether or other securing system.

"Once deployed by a lander on the surface, the IDDS autonomously drills into the ground under its own power," the paper stated. "The inchworm motion of the device's two segments both walks it forward and provides the thrust necessary for drilling. Feet on each segment grip the walls of the hole. Flights along the body pass cuttings to the rear."



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The drill, which would likely take weeks to make the plunge, would do observations of the surrounding environment once it arrived on Europa. It could even return to the surface when it was finished since the burrowing method doesn't need gravity.

At one time, NASA and the European Space Agency (ESA) were considering leading a joint mission called the Europa Jupiter System Mission – that could have also included a Russian lander – to head through the ice on the moon's surface. But with the mission proposed to cost billions of dollars, the project was eventually shelved when NASA ran into budgetary concerns. It did, however, bring public attention to another drill that could be used on the Jovian moon.

This drill would have heated up the ice to melt it, with rotating drill blades disposing of any debris as it buried deeper into the ice. In this case, however, NASA only planned to go about ten metres (33 feet) into the surface of the moon "because of the current state of technology". The drill would have required a cable, which could only be so long based on what the probe was able to carry.

Scientists eager to explore Europa could also take inspiration from Russian drills that were used to plumb beneath the icy surface covering Lake Vostok in Antarctica in 2012. It's possible that this expedition could provide clues for bacteria in the lake that has been separated from the outside world for millennia – similar to hypotheses about Europa.

Whatever form the drill takes, it's going to need to hitch a ride to Europa somehow. Perhaps findings from the upcoming Jupiter Icy Moons Explorer, due to launch in April 2023, will provide the push for a space agency or two to make the long voyage to the surface and under the ice.

"The inchworm motion both walks it forward and provides the thrust for drilling"

1 A compact drill
The drill would be only 1.5 metres (five feet) long, making it easy to fit into a spacecraft and light enough to make the long voyage.

2 Geysers
Geysers on the surface of Europa could hint at what lies below the surface if they are connected through the ice.

3 Mystery ocean
One major expectation is that an ocean lies below Europa's ice, but it's unclear what the ocean is made of and what lies within.

4 Digging in
Getting through the ice could require heat, vigorous drilling or a bit of both depending on the design of the drill.

5 Jupiter radiation
Jupiter is close to Europa and could make for a tricky radiation environment on the moon's surface.

6 A small window
The opening that the drill provides is enough to get the machine through and also provides a minimum of debris that must be flung aside.

7 On thin ice
Scientists aren't sure how thick the ice is – it could be perilously thin in places. The safety of any drill would need to be confirmed before penetrating.

7

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BIO+

Christopher J. Ferguson

Born on 1 September 1951, Ferguson is a retired US Navy Captain and NASA astronaut. He was the pilot on STS-115 in September 2006 and commander for STS-126 in November 2008 before serving as the final Space Shuttle commander aboard Atlantis for the STS-135 mission in July 2011. He now works at Boeing, where he has helped build a new generation of space vehicles with their CST-100 capsule under contract from NASA.

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Christopher J. Ferguson

"I really didn't know what to expect"

Ferguson reveals his regret at the retirement of NASA's iconic Space Shuttle, but tells us how excited he was to be working on the next generation of spacecraft at Boeing

Interviewed by Jonathan O'Callaghan

Why did you decide to become an astronaut?
I've always had this fascination with things I didn't completely understand. I spent a lot of time in the Navy only because I could never really understand how an aircraft carrier worked, I thought it was just one of the most intriguing places on Earth. So I was in the Navy for a good 15 years and then the next logical step, the next thing I really couldn't understand, was what it's like to operate in space. As I matured in my Navy career I realised I had been through most of the steps the early astronauts had done, and I thought I'd give it a go. I started applying as early as 1991 and I endured a couple of rejections, but as with most good things in life persistence certainly pays off and I finally got picked to join NASA in 1998.

Was it an exciting time to be involved in NASA's space program?
What a ride it was. It was kind of the heyday of the Space Shuttle program. The [International Space Station] was just coming online and we knew that we had an incredible amount of Space Shuttle flights, 35 in total, dedicated to the space station's construction. I don't think the public could truly appreciate the magnitude of the effort, but when you think about the fact there were 35 Space Shuttle missions, each of them carrying about 50,000 pounds [22,500 kilograms] of cargo into space, and not to mention the many Soyuz flights, Progress cargo flights and Proton flights with the Russian segments, it was truly a global construction effort and I look back at my time and think I was just so lucky to be a part of the whole thing?

How did it feel to be selected for your first flight as the pilot on STS-115?
There are few things in life that are comparable to getting selected to go on a spaceflight. I was just thrilled. Of course our training for that flight was delayed for over two and a half years because of what happened with Columbia, but like anything good it's worth waiting for in life. I flew in pretty quick succession, 2006, 2008 and then in 2011, so I was very, very fortunate. It's one of those moments in life you'll never forget, getting picked and realising boy, you know, you're really going to do this. So it was a great joy.

What was it like on your first flight?
I really didn't know what to expect. You hang around the office long enough and you begin to hear everybody's stories about their experiences, but while you can simulate most things, you can never simulate what it's like to be in zero-g. I remember a moment probably two or three minutes after launch when I looked out the window off to my right and saw the east coast of the United States disappear beneath us. And I looked outside, then inside, and outside again and I thought, 'You know, this is amazing. We are flying into space.' From that moment I was very aware how magnificent this was. Here I am in a spaceship that looks an awful lot like an aeroplane and we are literally flying this thing into space.

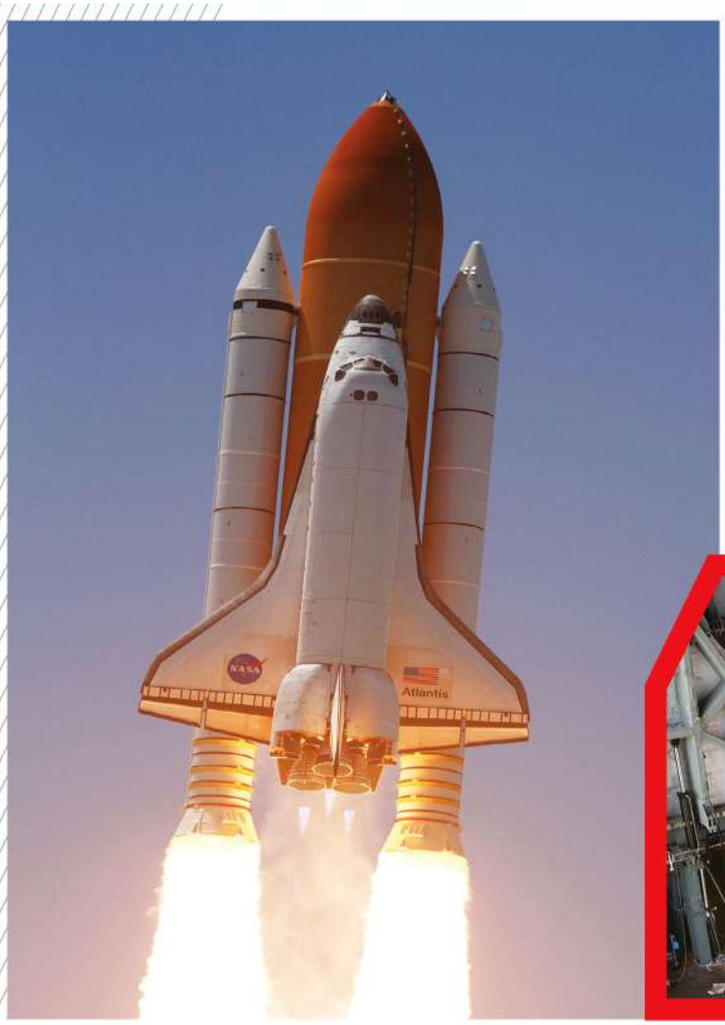
Having been a test pilot, how did it feel to pilot the Space Shuttle?
You're so prepared, especially for what we call the dynamic phases of flight, ascent and re-entry, but between all that it's completely different. It's a different world. You fly backwards, you fly upside down, and after a while you forget you're even in an aeroplane because it doesn't behave like one in orbit. You usually are upside down and backwards going tail-first looking at the Earth, and what a surreal experience that is. I can recall a moment we actually flew over a couple of hurricanes in the Atlantic Ocean, and to be able to look out the overhead windows straight into the eye of a hurricane is one of those 'pinch me' moments, when you can't believe you're actually doing what you're doing.

What was it like to be chosen as the commander for the final Space Shuttle flight, STS-135?
It was sort of a mixed blessing for me. I knew my name was up in the rotation [for this mission] but it was a flight that might not happen, it was kind of like being a part of Apollo 18 [laughs]. Then the Space Act of 2010 kind of baselined the Congressional funding for this additional flight [so it went ahead]. But what I realised not too far into training was that I was not just a crew member on a Space Shuttle flight, but it was sort of my job to say goodbye to everybody, folks that had worked an entire career on this vehicle. They knew they were going to head into retirement at best and perhaps at worst they were going to lose their job in the middle of their career. So it became a very delicate balancing act to kind of sing the praises of the Shuttle program as a whole, and at the same time respect and acknowledge the people who were soon going to lose their jobs who had been a part of it for so many decades.

Was it the right decision to retire the Space Shuttle?
If you had asked me back in 2003, which is when the decision was made to retire the Shuttle, I would have said, of course this is right, after losing Columbia. Losing two out of the five Space Shuttles is not great odds, and if we continued to fly this thing for another 20 years, chances were we were going to lose another one. So at the time I would've said, knowing that something else was on the horizon, it's probably not a bad idea for us to move on. But as the days got closer, and then the Obama administration cancelled the Constellation program [in 2010], we realised there was going to be a substantial gap between the Shuttle and whatever followed it. At those moments I gave pause and

Ferguson was the commander on the final flight of the Space Shuttle

The Boeing Starliner is an ambitious program that Ferguson is currently working on



regretted feeling the way I did back in 2003, that it was a good idea to shut the Shuttle program down. I think looking at all the events that had transpired between 2003 and 2010 the wise thing would have been to preserve America's access to low-Earth orbit [LEO] and to continue flying the Shuttle until we had clear direction and an approved plan by Congress to get back to LEO at a defined date. We're in that gap now, which is what I'm a part of with Boeing, but after realising the impact of it I would have said we should keep flying it perhaps just twice a year to know that we can get [to LEO] and we're not reliant exclusively on the Russians.

The Space Shuttle was instrumental in the construction of the ISS

What was the most notable moment from that final flight?
One in particular was the night before re-entry. The last flight control team had come into the flight control centre and I had the opportunity to expound a little bit on my thoughts with them, and tell them all to just enjoy the moment and to thank them profusely on behalf of all the astronauts for what they have done throughout the years. Those one-on-one discussions with the flight control teams as they left was probably the most noteworthy memory from that last flight.

Following the retirement of the Shuttle, why did you decide to join Boeing?
I'd been talking to Boeing on and off before the flight, and then afterwards I knew Boeing was one of the potential providers for what we call [NASA's] Commercial Crew service along with SpaceX and Sierra Nevada Corporation. And I knew Sierra Nevada had their astronaut, SpaceX had theirs, but Boeing didn't have one. When I say 'their astronaut', it's just nice to have somebody on board helping guide the development of the interior of the spacecraft from a crew's perspective and to make sure it satisfies the intent of the mission. We have a lot of experience, over 50 years of flying in space, and the astronauts really are the ones who know how a craft operates in space. Here was an opportunity to join a company who was potentially working on the next craft that will launch from American soil and take astronauts up, and I thought how can I possibly turn something like this down. And I haven't looked back, it's been a joy ever since I got to Boeing about a year and a half ago.

Was it exciting to be working on the next generation of space vehicles with Boeing's CST-100 capsule?
Yeah, and I tell everybody working with me and for me that to actually build a spacecraft is not just a once in a lifetime opportunity, it's a once in a multi-generation opportunity. I mean the last time we did this was in the mid-70s as we were designing the Space Shuttle, and a lot of the people associated with that work have retired or are no longer with us, and that was a long time ago. So a lot of this we're having to re-learn, but I'm absolutely amazed at the depth and breadth that Boeing has and their ability to resurrect this latent talent that it had within, because you know Boeing's been involved in just about every human spacecraft since the Mercury days. I look at this team I'm working with and I'm humbled in their presence because I thought I knew it all, but in reality I knew very little.

Is the privatisation of spaceflight important for the future of space travel?
I think about it in terms possibilities. I envision a Boeing astronaut heading to their vehicle outfitted in Boeing regalia. Now you've got really the first vestiges of a commercial spaceline where anybody with a lot of money, at least in the early stages of the program, could do something like this. Air travel was the same way initially back in the 1920s when it started to take-off, only the wealthy did it. Rocket travel to LEO will be just the same way initially, but the more you do it the more confidence that the public has in your ability to do it safely and the more customers you fly you begin to get into economies of scale and suddenly it's within the grasp of people who would never have been able to consider something like this even ten years ago. So from that perspective I think it's very exciting. A commercial pilot taking a commercial paying crew into space is just mind-boggling if you think about it, but I can see in ten years it being a distinct reality.

"While you can simulate most things, you can never simulate what it's like to be in zero-g"

© NASA

FOCUS ON

WATER ON MARS

China's rover suggests the liquid may have been on Mars much more recently than scientists thought

Reported by Andrew Jones

Evidence is growing that Mars, now cold and dry, had liquid water running on its surface much more recently than previously thought. Scientists have long believed that Mars was wet around 3 billion years ago, during the planet's Hesperian period, then lost much of its water. But a new study presents evidence of water activity from just 700 million years ago, well into the current Amazonian period, posing a new puzzle to crack about the Red Planet and its history.

The new study is based on data from China's Zhurong rover, part of the Tianwen-1 mission that touched down on the surface of Mars in May 2021. In particular, the scientists used data the rover gathered during its first 92 Martian days, or sols, at its landing site in Utopia Planitia. Yang Liu, a researcher at the National Space Science Center (NSSC) under the Chinese Academy of Sciences (CAS), and colleagues analysed data from three different instruments on Zhurong: the laser-induced breakdown spectrometer, the telescopic microimaging camera and the short-wave infrared spectrometer.

Those instruments studied minerals that suggest the presence of a substantial quantity of liquid water at the site about 700 million years ago, which scientists previously thought was dry. "This is a very interesting result," says Eva Scheller, a planetary scientist at the California Institute of Technology who wasn't involved

Mars was much more Earth-like before its atmosphere was lost

> "It means that particular forms of water-bearing minerals would have formed at much later time periods than have previously been considered"
>
> **Eva Scheller**

in the new research. "We have very little recorded evidence of 'young' liquid water systems on Mars. And for the ones we have, they were usually in the form of salt minerals." But Zhurong's instruments spotted water molecules locked away in the rock, "which is very interesting and different from other young liquid water environments that have been observed," Scheller explained. "It means that particular forms of water-bearing minerals would have formed at much later time periods than have previously been considered in other scientific studies."

NASA has so far sent its Mars rovers to ancient landing sites, dating back to the Noachian age more than 3.7 billion years ago. Zhurong is not just an extra set of wheels on Mars, but a powerful suite of instruments exploring a new, geologically young site to open new windows of opportunity for research on Mars.

"One of the major things we'll have to find out and that I look forward to seeing from the Zhurong rover is how extensive these 'young' water-bearing minerals are," Scheller said. "Are they common or uncommon in these 'young' rocks?" Zhurong has now covered about two kilometres (1.24 miles) during its more than 350 Martian days and has analysed a range of features on its travels, meaning more new Martian insights are likely still to come from the rover.

LAYERS OF THE RED PLANET

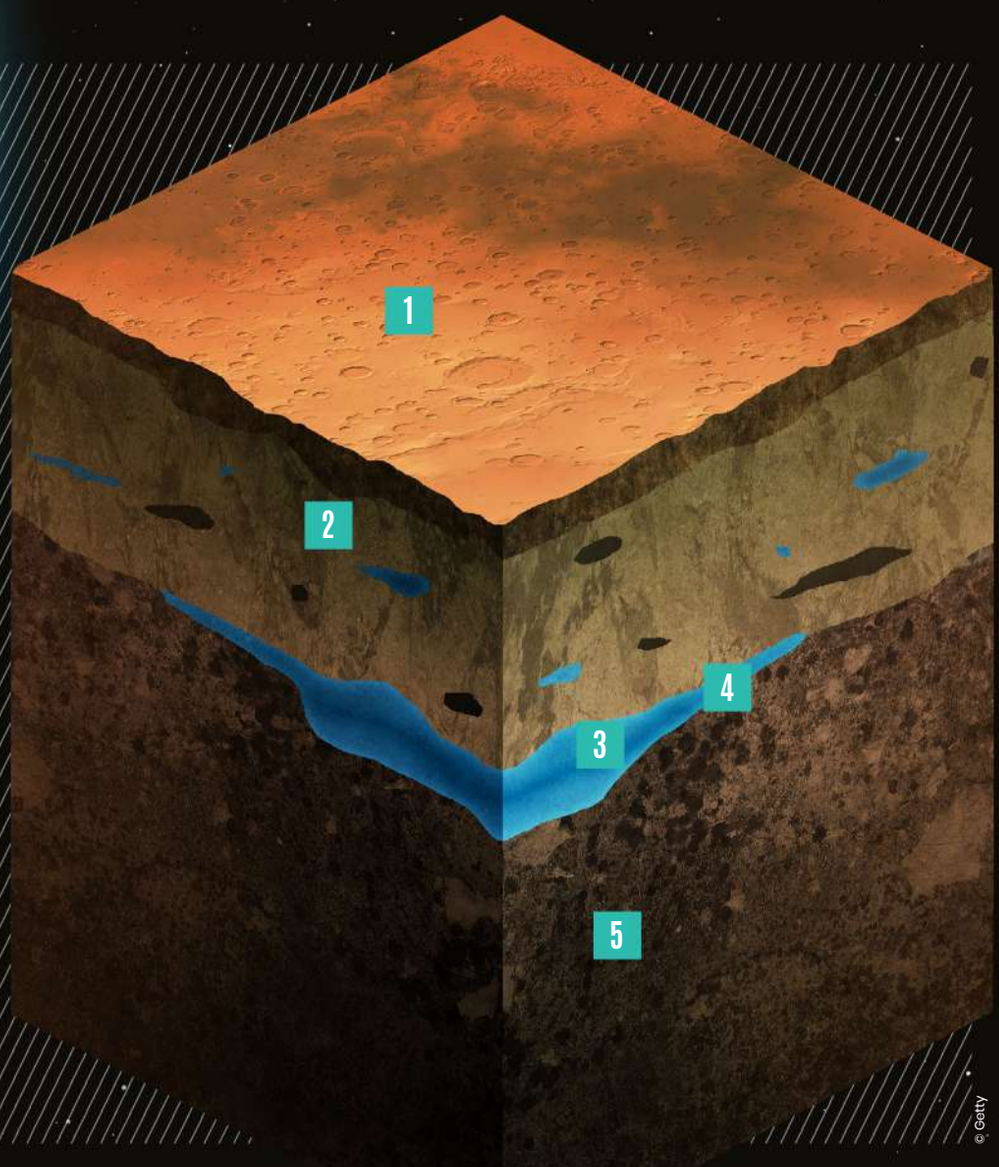
1 Dry soil
Martian soil forms a dusty layer. It's made up of nutrients such as sodium, potassium, chloride and magnesium.

2 Signs of ice
Surface ice is thought to have become buried, leaving a permafrost subsurface with young ice in its pores.

3 Pockets of water
Water ice is locked within cavities across the mid-latitudes of the planet. Some chunks of frozen water have been found just beneath the surface.

4 Subsurface reservoirs
Lakes are thought to exist far beneath the surface. A high level of salt or heat from Mars' interior could even result in them being liquid.

5 The foundation
The water would lie above an impermeable bedrock, with a high concentration of sulphur.



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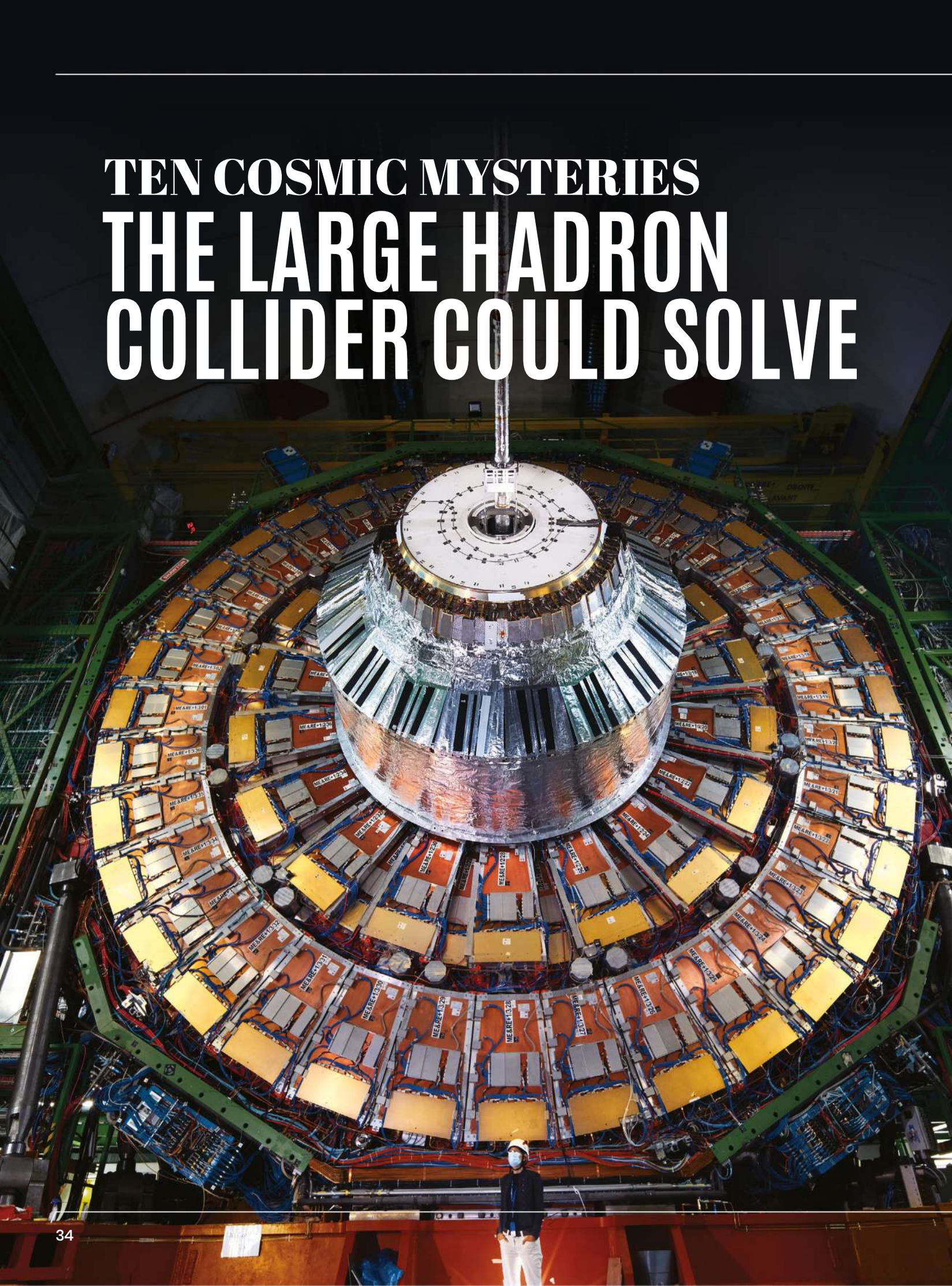
TEN COSMIC MYSTERIES

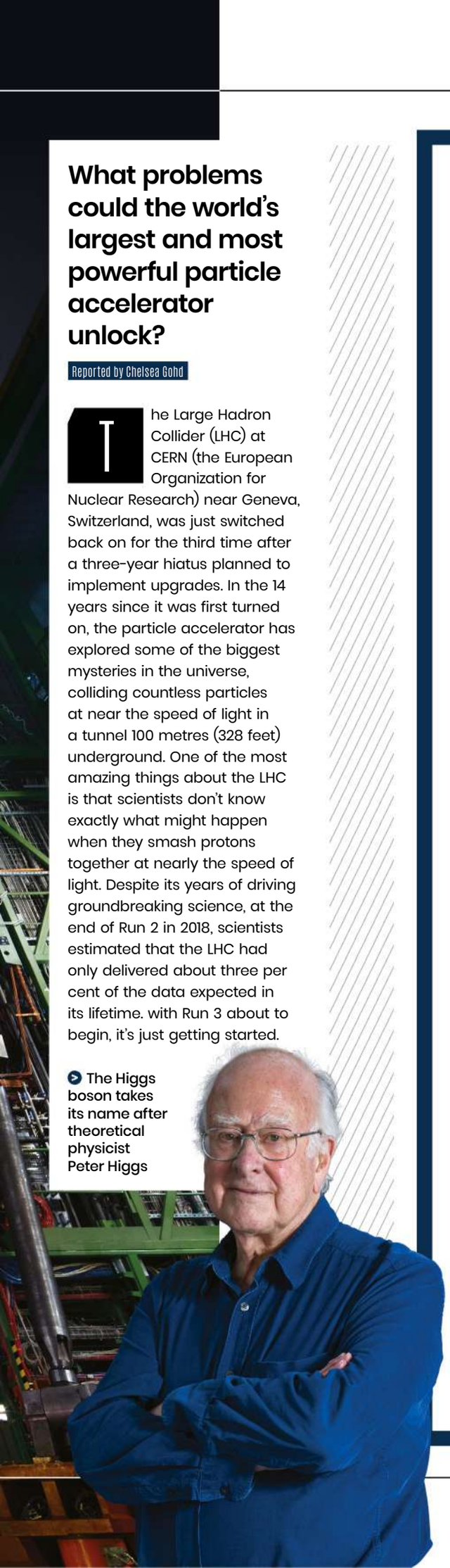
THE LARGE HADRON COLLIDER COULD SOLVE



What problems could the world's largest and most powerful particle accelerator unlock?

Reported by Chelsea Gohd

The Large Hadron Collider (LHC) at CERN (the European Organization for Nuclear Research) near Geneva, Switzerland, was just switched back on for the third time after a three-year hiatus planned to implement upgrades. In the 14 years since it was first turned on, the particle accelerator has explored some of the biggest mysteries in the universe, colliding countless particles at near the speed of light in a tunnel 100 metres (328 feet) underground. One of the most amazing things about the LHC is that scientists don't know exactly what might happen when they smash protons together at nearly the speed of light. Despite its years of driving groundbreaking science, at the end of Run 2 in 2018, scientists estimated that the LHC had only delivered about three per cent of the data expected in its lifetime. with Run 3 about to begin, it's just getting started.



The Higgs boson takes its name after theoretical physicist Peter Higgs

THE HIGGS BOSON

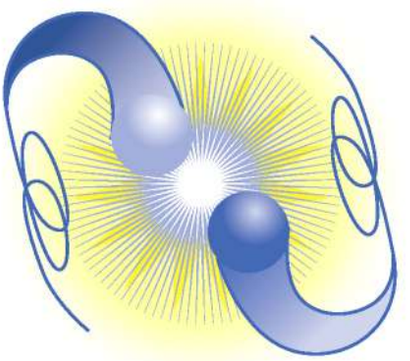
Probably the most famous discovery to come out of the LHC to date, the Higgs boson is an elementary particle, the existence of which was confirmed in 2012 at the LHC. But there is still a lot to be learned from studying the strange particle.

The particle is associated with what is called the Higgs field, which gives mass to other elementary or fundamental particles like electrons and the quarks that make up protons. The particle even gets its own mass from interactions with the Higgs field. But not all fundamental particles have mass: the photon, or light particle, has no mass, for example.

There remain many mysteries about the Higgs boson. With future experimentation at the LHC, particle physicists could paint a more complete picture of this strange particle. LHC scientists have already observed the Higgs particle doing strange things ever since they spotted it, offering additional mysteries to solve.

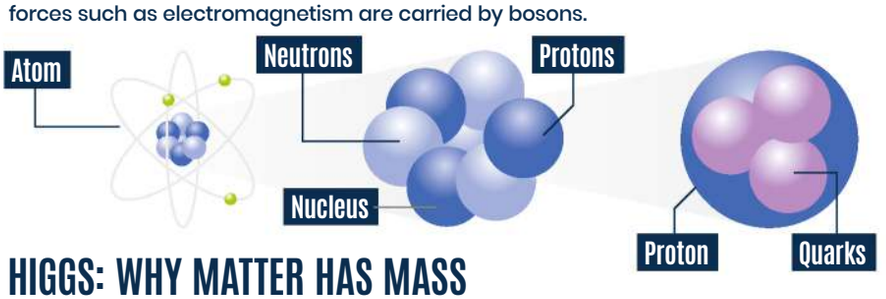
FINDING HINTS OF HIGGS

Was mass mediated by the Higgs boson? That's what the LHC tried to find out by using electromagnetic fields to whip beams of protons around and around to nearly the speed of light. When these protons collide, energy is released and new particles are made, which can provide evidence for the Higgs boson.



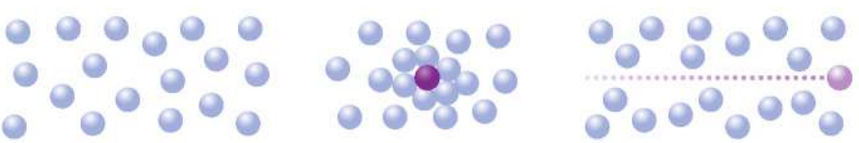
MASS AND MATTER

Matter particles, such as those that constitute atoms, contain mass. These particles come in two categories: fermions include quarks and leptons, while forces such as electromagnetism are carried by bosons.



HIGGS: WHY MATTER HAS MASS

Particles may be more massive than one another because they feel the Higgs field differently. It's because of the Higgs boson that matter has mass.



Meeting the field

The Higgs field occurs everywhere throughout the universe and gives matter particles – as well as Higgs bosons – their mass.

Enter ordinary matter

When matter moves through the Higgs field, it becomes excited and forms Higgs bosons. These cluster around a particle to give it mass.

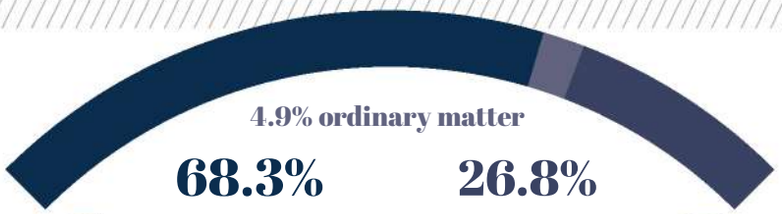
High-speed photons

Some particles move through space without interacting with the Higgs field. This means they don't gain any mass from Higgs bosons.

© CERN; Getty

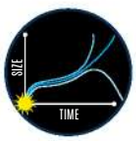
DARK ENERGY

2 While its name might seem to imply that dark energy is similar to dark matter, their connection lies in the name alone. In addition to their similar names, dark energy is also invisible and expansive. Dark energy is a mysterious force suspected to make up nearly three-fourths of the universe, and scientists think it's causing the expansion of the universe to speed up. While the LHC is designed to experiment with particles, some theorists have suggested that if dark energy is a type of force or field, then the LHC could be used to investigate that idea, similarly to how the LHC used the Higgs field to produce the Higgs boson. As physicist Clare Burrage describes: "Cosmologists know that there is new physics we don't understand, and all the evidence is pointing towards something very fundamental about our universe."



Supernova evidence

Key evidence for dark energy comes from Type 1a supernovae – collapsing stars that always reach the same peak brightness.



Expansion curves

The nature of dark energy affects whether expansion of the universe reverses, continues or speeds up.

Heading for a Big Rip?

The effects of dark energy seem to have grown stronger. If this continues, cosmic acceleration could tear everything apart.

Alternatives

Some cosmologists think evidence for dark energy could be explained by modifications to known theories of gravity.

Missing mass

In the 1930s, Fritz Zwicky first identified huge amounts of dark matter through the motion of galaxies within clusters.

Galactic rotation

In the 1970s, astronomers found that the gravity of this unseen matter also affects the orbits of stars in galaxies.

Planets or particles?

Some dark matter is probably 'normal' dense, non-luminous objects like planets, brown dwarfs or black holes.

Gravitational lensing

We can trace dark matter by measuring the way galaxy clusters warp and deflect light from more distant objects.

DARK MATTER

3 Scientists hope with the help of the LHC they will be able to find particles that constitute dark matter, the never-before-observed stuff that makes up 27 per cent of all matter in the universe. We can't see dark matter, but we know it's there because we can see its effects. "Dark matter is most of the matter in the universe, and we have no idea what it is. One of the most outstanding questions in all of science is what dark matter is," Benjamin Safdi, an assistant professor of physics at the University of California, Berkeley, whose research includes investigating possible explanations for dark matter, says. Scientists have a number of different dark matter candidates – strange particles that could be the elusive dark matter. But while the culprit hasn't yet been identified, the LHC remains a powerful tool that scientists will continue to use to solve this major mystery.

WIMPS

4 In terms of dark matter, one of the candidates that's gotten serious attention over the years has been weakly interacting massive particles, or WIMPs, which the LHC has already investigated. WIMPs are hypothetical particles that are said to interact via forces including gravity and might exist outside of the Standard Model. "The LHC has really broken new ground in the search for dark matter in the form of weakly interacting massive particles," dark matter theorist Tim Tait of the University of California, Irvine, involved in the LHC Dark Matter Working Group, says. So far the LHC has attempted to spot this dark matter candidate. Scientists have used the LHC to look for WIMPs by searching for signals of what might be created by, for example, WIMPs interacting with ordinary matter. But "all of the observed results have been consistent with models that don't include dark matter," Tait says.

AXIONS

5 Axions are another hypothetical elementary particle that have been in the spotlight. The axion, proposed in 1977, has both low mass and low energy; in 2020, physicists found the first direct evidence of axions and fanned the flames of interest in the particle as a dark matter candidate. Especially following the 2020 findings, the axion is growing in popularity as a dark matter candidate. But no one has yet 'caught' an axion by directly detecting the particle in an accelerator like the LHC.

Scientists have proposed a number of possible experiments that could be used to try and 'catch' an axion, but as researchers described in a 2018 CERN statement, the LHC can be used to search for a new, hypothetical particle: the QCD axion. Even though physicists haven't yet 'caught' either, it's possible that future experimentation with the LHC might shed new light on this particle mystery, potentially confirming scientists' suspicions about the axion or finding new information that changes existing ideas entirely.

GHOST PARTICLES

6 Neutrinos, nicknamed 'ghost particles' because of their elusive nature, were spotted for the first time in a particle accelerator in 2021. The discovery was made at the LHC and has opened up a whole world of subatomic mysteries. Neutrinos are subatomic particles with no electrical charge and such a small mass that scientists used to think they had no mass at all. Neutrinos are thought to be one of the most prevalent particles in the entire universe; every second, about 100 billion neutrinos pass through every square centimetre of the human body. These particles, produced in the hearts of stars through nuclear fusion, are just about everywhere. But because neutrinos don't interact much with matter – they only interact via gravity and the weak force – and because of their lack of charge and tiny mass, they have been remarkably difficult to spot in particle accelerators. The LHC's landmark 2021 detection changed that, and with this big 'first' accomplished, the LHC can now push this science forward, further exploring the ghostly particles that permeate our universe.

"Neutrinos are subatomic particles with no electrical charge"

WHAT THE GHOST PARTICLE TELLS US

They solve a 100-year-old mystery

The source of high-energy cosmic rays has been one of astronomy's greatest mysteries. Neutrinos are created along with the other particles that make up cosmic rays, and because they are impervious to magnetism and gravity, they tell us where cosmic rays come from.

They break the rules

Because they can spontaneously change mass, or flavour, on the fly, neutrinos seem to break the rules that describe nature at its most fundamental. Figuring out how neutrinos do this could help physicists develop new theories.

They are uncorrupted

Unlike almost every other particle, neutrinos can travel through space without being blocked by matter like clouds of dust, stars, planets or even galaxies. Any information they carry will be totally uncorrupted.

They could tell us why anything exists at all

After the Big Bang, matter and antimatter were created in equal measure. As such, they should have obliterated each other. The fact that anything exists shows that for some reason matter won out. Could the neutrinos' strange mass-changing abilities have tipped the scales and allowed matter to win?

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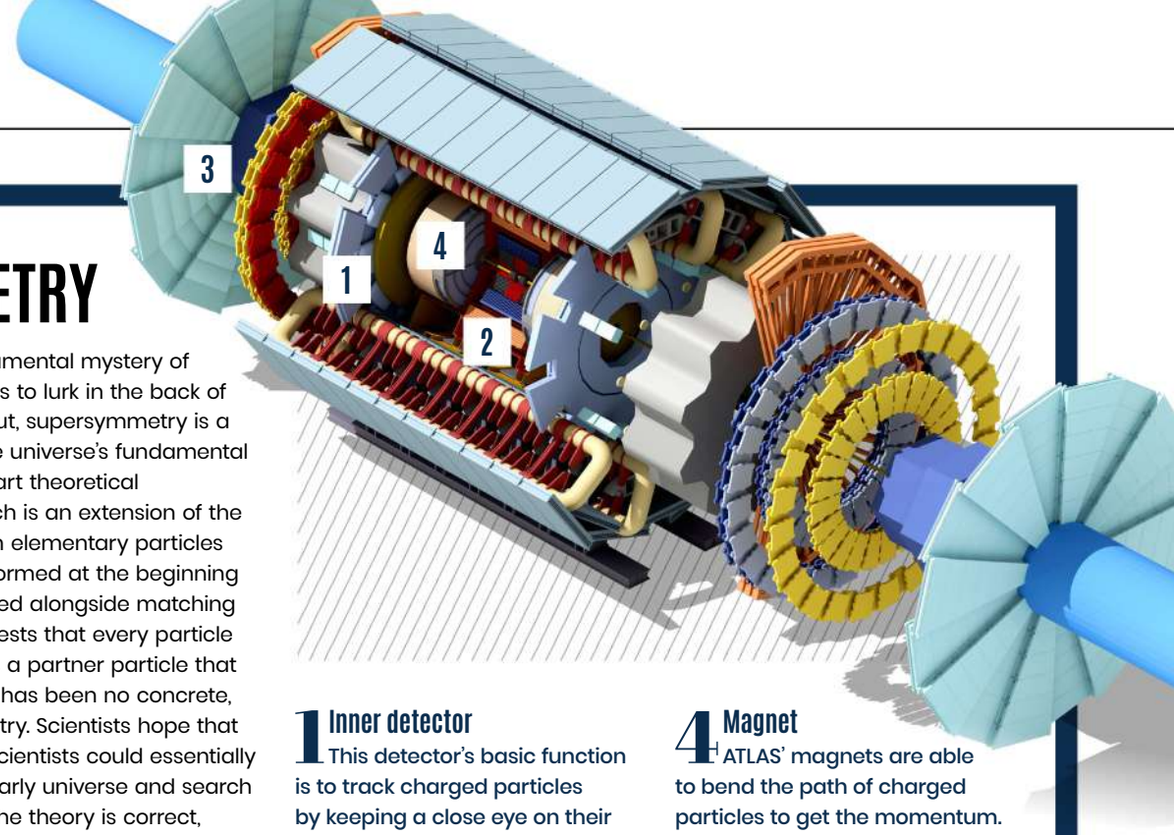


SUPERSYMMETRY

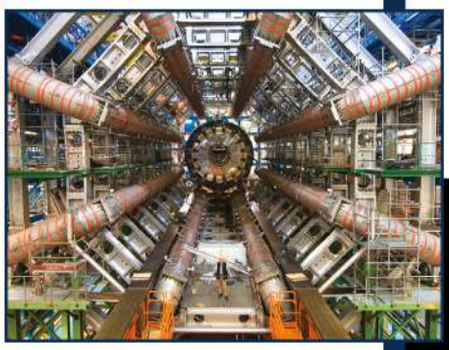
Supersymmetry is a fundamental mystery of the universe that continues to lurk in the back of scientists' minds. Simply put, supersymmetry is a theory suggesting that all of the universe's fundamental particles should have counterpart theoretical 'superparticles'. This theory, which is an extension of the Standard Model, says that when elementary particles like photons or electrons were formed at the beginning of the universe, they were created alongside matching superparticles. The theory suggests that every particle seen in the Standard Model has a partner particle that spins differently. However, there has been no concrete, direct evidence of supersymmetry. Scientists hope that by using a facility like the LHC, scientists could essentially recreate the conditions of the early universe and search for signs of supersymmetry. "If the theory is correct, supersymmetric particles should appear in collisions at the LHC," CERN says. Scientists have previously wondered whether the LHC is creating supersymmetric particles that are escaping the detector, then decaying. And since experiments like ATLAS (A Toroidal LHC ApparatuS), the largest general-purpose experiment at the LHC, detect particles' decay and the products of that decay rather than the particles directly, physicists remain concerned about how these particles could be detected if they are indeed there. With this mystery lingering, it makes new opportunities for exploration with the LHC all the more exciting.

1 Inner detector
This detector's basic function is to track charged particles by keeping a close eye on their interactions with materials inside ATLAS.

2 Calorimeters
The purpose of the calorimeters is to measure the energy from particles.

3 Spectrometer
ATLAS has a spectrometer that allows it to work out the momentum of muons.

4 Magnet
ATLAS' magnets are able to bend the path of charged particles to get the momentum.



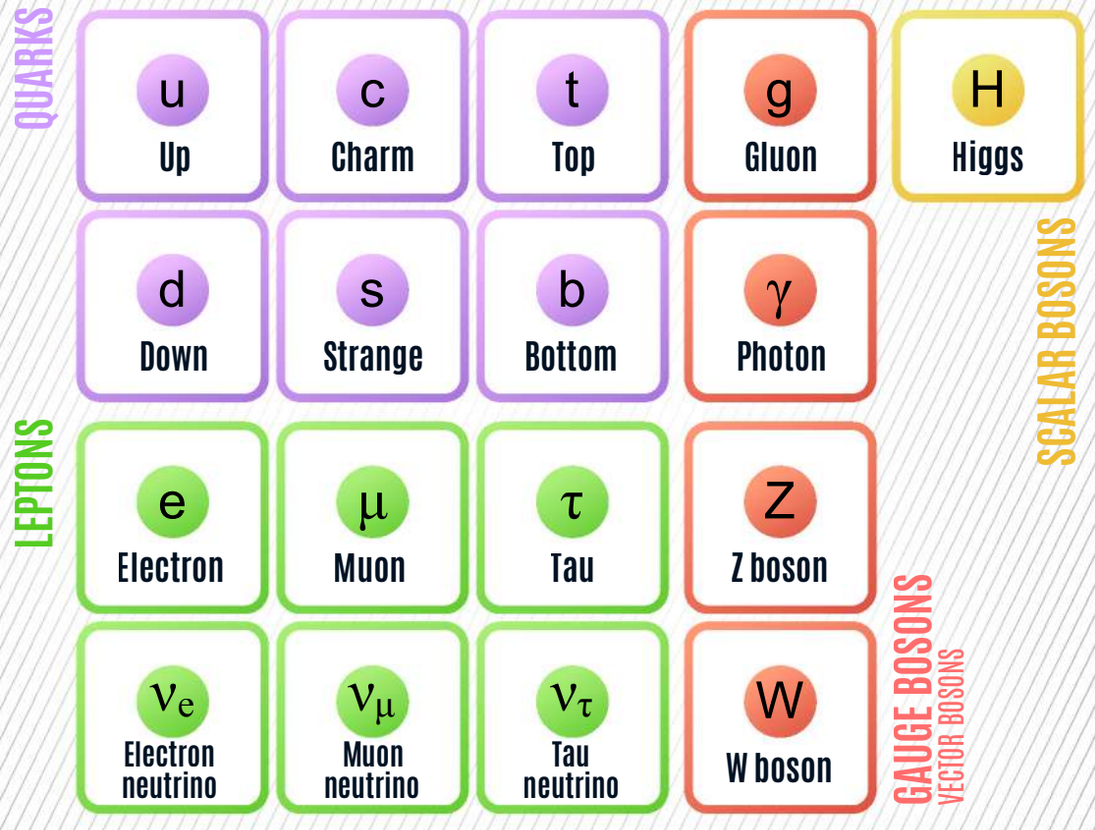
ASYMMETRY PROBLEM

One of the biggest mysteries in science remains– what is known as 'matter-antimatter asymmetry'. As we understand it, the Big Bang should have created nearly equal amounts of matter and antimatter in the early universe. But the universe today appears to be primarily composed of matter, with very little antimatter. This mystery asks what happened. Scientists believe that the Big Bang created a 'nearly equal' amount of antimatter and matter because if there was the exact same amount, the two types would have essentially cancelled one another out, leaving behind an empty universe. But that slight asymmetry between matter and antimatter following the Big Bang isn't fully explained by the Standard Model, and physicists are also unsure how this slight asymmetry led to the matter-dominated universe that we live in today. With the Large Hadron Collider beauty (LHCb) experiment, scientists have investigated slight differences between matter and antimatter.

"The mystery asks what happened during the Big Bang"

MYSTERY PARTICLES

9 If the world's largest and most powerful particle accelerator is good at one thing, it's smashing particles together. This technology has enabled incredible steps forward in the field of particle physics, including creating and observing strange new particles that scientists had only suspected might exist. From 2011 to 2021, scientists using the LHC discovered 59 new types of hadron particles. Among those, in 2018 they found a strange 'mystery particle'. In 2021, a rare four-quark 'tetraquark' particle, a non-elementary particle, was spotted at the LHC. And the Higgs boson discovery at the LHC certainly counts as a remarkable particle find. As researchers continue to smash protons near the speed of light and explore the fringes of what we know to be true about the universe, it's likely that strange new particles will continue to pop up during the LHC's new operational phase.



THE STANDARD MODEL

10 The last item on this list is almost an honourable mention, but it remains one of the most significant, all-encompassing objectives that scientists use the LHC to investigate. The Standard Model of particle physics describes all known forces and particles in the universe – it's the best 'theory of everything' that scientists have to work with. But the Standard Model isn't complete, and as we explore major unknowns like dark matter and dark energy, researchers continue to explore how they might need to extend the Standard Model. The LHC allows scientists to both confirm what we already suspect about the Standard Model and also see where the model falls short, and whether physicists may need to extend the theory or break the model apart altogether.

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FOCUS ON

CHINA IS ON THE HUNT FOR EARTH 2.0 WITH PROPOSED SPACE TELESCOPE

If approved, the mission will launch in 2026

Reported by Andrew Jones

China could soon begin its first space-based hunt for exoplanets if a proposal from the Shanghai Astronomical Observatory (SAO) gets the go-ahead this summer. The new telescope would spend four years orbiting Sun-Earth Lagrange point 2, about 1.5 million kilometres (930,000 miles) from Earth. Once there, it would fix its seven telescopes on a portion of the sky towards the galactic centre and watch for signs of dimming as planets pass in front of their star as they orbit. The main targets are roughly Earth-size exoplanets with similar orbits around Sun-like stars. This requires high sensitivity to spot the signals of small-planet transits, as well as long-term monitoring to glimpse planets that take an Earthly year to go around their star.

The Earth 2.0 telescope wouldn't be able to confirm an Earth twin on its own; it would measure planets' sizes and orbital periods to identify candidates for follow-up observations for potential habitability, Ge Jian, a professor at the SAO, said. "These planet candidates can be followed up with ground-based telescopes to obtain radial velocity measurements to determine their masses and densities," Ge said. "Some of these planet candidates around bright stars can be further followed up with ground-based or space-based spectroscopy to obtain transmission spectra to study their atmospheres' compositions."

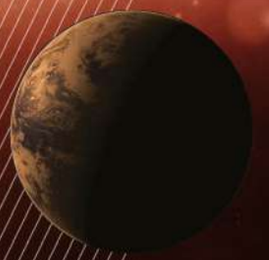
The Chinese mission would follow up on observations of an area of space that NASA's Kepler space telescope studied for nine years, but the Earth 2.0 satellite would have a much greater field of view, meaning it would be able to observe a larger area and more stars.

Kepler's field of view was 115 square degrees; it observed half a million stars

TOP FIVE EARTH-LIKE WORLDS

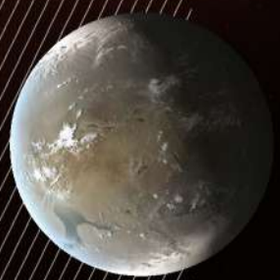
Kepler-438b

Announced as a confirmed exoplanet in 2015, this world has a radius 1.12 times that of Earth. It rests in the habitable zone of its red dwarf – a star that's cooler and smaller than our Sun – and astronomers believe that this planet is the most Earth-like to date.



Gliese 667Cc

Able to complete one lap around its parent star in just 28 days, Gliese 667C is a red dwarf that lies 22 light years away in the constellation of Scorpius. Gliese 667Cc isn't the only planet that's a member of this system. One of two confirmed worlds, this rocky super-Earth is at least 3.9 times more massive than Earth.

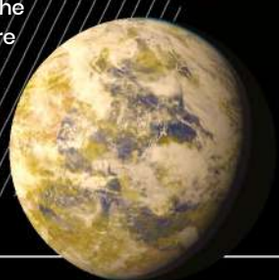


Kepler-442b

Discovered by Kepler, Kepler-442b orbits an orange dwarf star 1,120 light years from Earth. It completes its orbit in roughly 112 days and has a radius 1.3 times that of Earth. It is thought to have a comfortable temperature similar to that of our planet.

Kepler-62e

Astronomers believe that this exoplanet is a water world, a warm place that's surface is dominated by liquid water. Kepler-62e lies some 1,200 light years away and takes 122 days to complete one lap around its red dwarf host.



Gliese 832c

This hefty world orbits a red dwarf star and weighs in at around 5.4 times the mass of Earth. It's thought that on the whole this planet has a temperature similar to Earth. Yet with an orbit that sees the exoplanet swing in and out of the habitable zone, Gliese 832c's climate can vary.

and discovered 2,392 exoplanets, with a similar number of candidate planets awaiting confirmation. Although the telescope detected some terrestrial planets, none around Sun-like stars were potential Earth twins. The Earth 2.0 telescope, in comparison, would cover 500 square degrees and monitor 1.2 million dwarf stars for four years with six of its seven 30-centimetre (11.8-inch) aperture telescopes. The apparent area of the Moon in the sky is about 0.5 square degrees, while the whole sky is about 41,000 square degrees. The telescope would also be able to view dimmer and more distant stars, adding to its survey capabilities.

"As the transit method is a statistical game, the more suitable solar-type stars you search, the higher chance you would detect an Earth 2.0," Ge said. "If the Earth 2.0's occurrence rate is ten per cent, then we need to search roughly 2,000 relatively bright, quiet solar-type stars to detect an Earth 2.0's transit.

"Our survey simulations show that we expect to detect about 30,000 new planets, including around 5,000 terrestrial-like planets by our mission," Ge said, adding that the six-telescope design and better signal-to-noise-ratio detectors would also boost its capabilities. The seventh telescope, meanwhile, would have the sensitivity to detect cold or free-floating rocky planets – also known as rogue planets – as small as Mars by looking for the effects of a planet's gravity bending starlight as it passes by.

It would also be able to spot cold planets orbiting stars at distances comparable to those at which Uranus and Neptune orbit the Sun. "The ability of the Earth 2.0 telescope to continue the survey started by Kepler – and extend this to planets on longer and cooler orbits – is incredibly exciting," said Elizabeth Tasker, an associate professor at the Japan Aerospace Exploration Agency. "Our current exoplanet discoveries have not yet been able to probe these regions thoroughly, leaving us unable to properly mine the data to seek trends and patterns that would tell us how planets form, including rocky worlds in similar orbits to Earth."

"Our current exoplanet discoveries have not yet been able to probe these regions"

Elizabeth Tasker

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PLANET PROFILE

JUPITER

The largest planet has a lot to tell us, and Juno is on the case

Fifth in the eight-planet lineup of our Solar System, Jupiter also happens to be the largest, and by quite some distance. The mass of this gigantic ball of gas is two-and-a-half times that of all the other planets put together, and you could fit 11.2 Earths within its radius. While there's likely a rocky core somewhere under the enormous gaseous atmosphere, scientists can't be sure whether it's solid or not, but gravitational measurements suggest it could make up as much as 15 per cent of Jupiter's mass.

What is known is that Jupiter is contracting, and this generates more heat than the planet receives from the Sun, warming the huge number of moons that orbit around it. It also has a faint ring system – too thin to be seen from Earth with any but the largest telescopes and first spotted by the Voyager 1 probe in 1979.

Jupiter plays a major role in many theories of the formation of our Solar System. In the grand tack hypothesis, Jupiter formed at 3.5 astronomical units (AU) – 1 AU is the Earth-Sun distance – before plunging inward towards the Sun until it reached 1.5 AU, then reversing course and moving out again, stopping at its current distance of 5.2 AU. It crossed the asteroid belt twice, scattering rocks in all directions and contributing to the low mass of the belt today. It may also have caused rocky planets orbiting closer to the Sun to crash into the star's surface. This answers questions such as why Mars is so small – Jupiter's presence limited the material available for its formation – and why there are no large planets orbiting close to the Sun, as we see in other solar systems.

Jupiter has also had a long-lasting effect on the rest of the Solar System. It has a fleet of asteroids and comets that follow it through its orbit – over 2,000 have been discovered – and its great mass means that the centre of gravity for it and the Sun lies above the Sun's surface, meaning they act almost like a binary system. The giant planet's gravity well also means it can intercept comets and asteroids heading into the inner Solar System and may partially shield the inner planets from bombardment. Another theory is that it draws small bodies in from the Kuiper Belt. Whichever is true, Jupiter experiences 200 times more impacts than Earth.

Galileo discovered Jupiter's four largest moons, known as the Galilean moons, in 1610 – the first time moons had been observed around another planet. Humanity has since explored the planet with observatories and space probes, beginning in 1973 with a flyby by Pioneer 10. Many missions to the outer Solar System have used Jupiter's gravity as a slingshot to correct their course or gain speed, but the first craft to orbit the planet was the aptly named Galileo in 1995.

The hazy northern hemisphere of Jupiter processed by citizen scientist Gerald Eichstädt from Juno camera data in 2020

A cyclonic storm in Jupiter's northern hemisphere, taken by Juno in 2019

Atmospheric composition

Upper atmosphere

90%
HYDROGEN

10%
HELIUM

Lower atmosphere

71%
HYDROGEN

24%
HELIUM

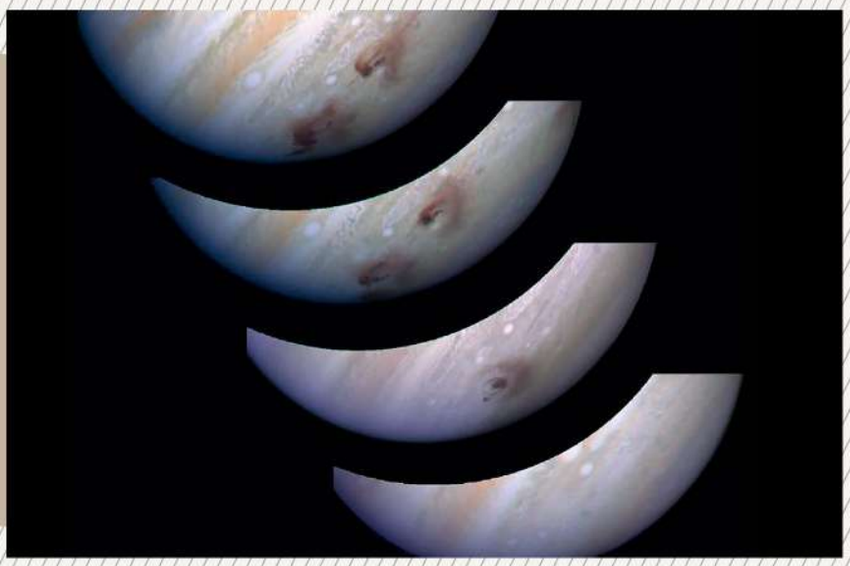
5%
OTHER ELEMENTS

© NASA

NEWS FROM JUPITER

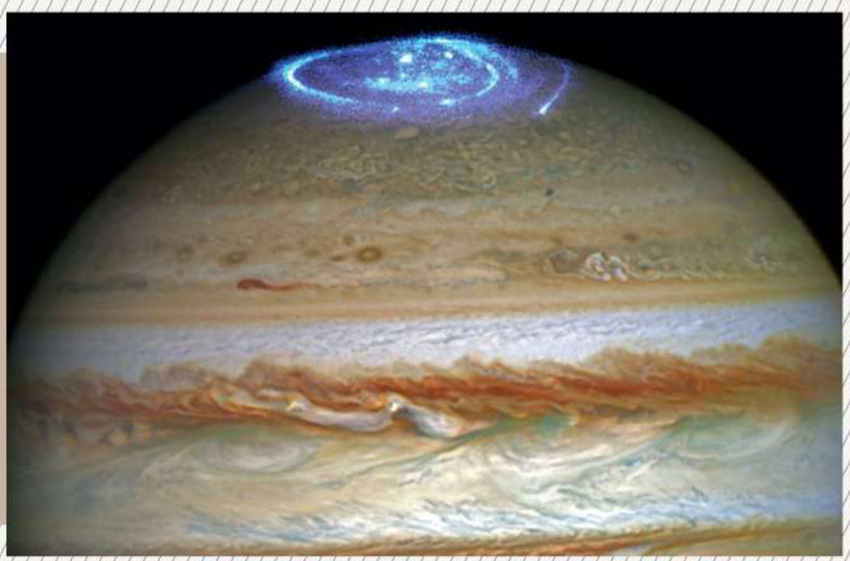
Wind speeds measured

Scientists have directly measured the winds in the middle of Jupiter's atmosphere. Using the Atacama Large Millimeter/submillimeter Array (ALMA), a team was able to track the movement of molecules of hydrogen cyanide in the planet's turbulent atmosphere, measuring narrow bands of wind at up to 1,448 kilometres (900 miles) per hour. Hydrogen cyanide is not native to Jupiter, but was added when Comet Shoemaker-Levy 9 collided with the planet in 1994. Since then it has been circling the atmosphere. Using 42 of ALMA's 66 high-precision antennae, a team measured the Doppler shift, tiny changes in the radiation emitted by the molecules, from which they were able to deduce wind speed.



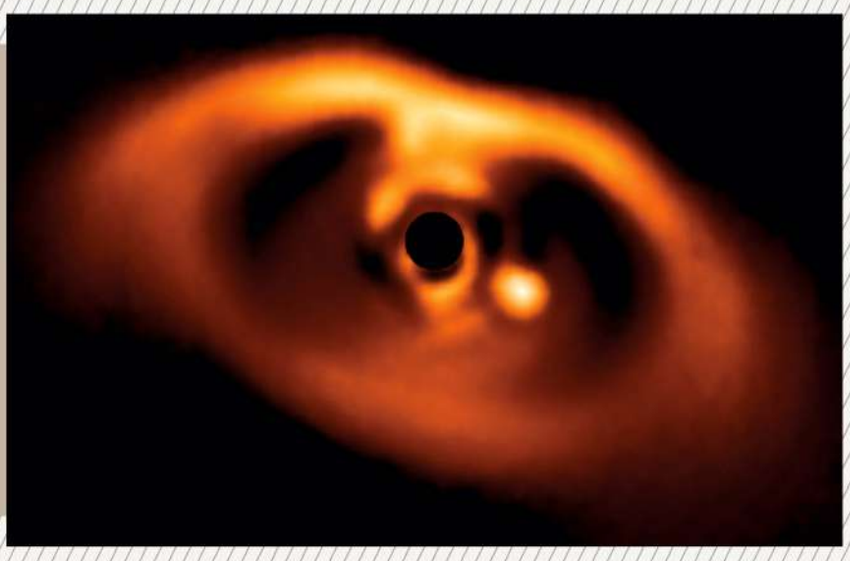
Auroral activity

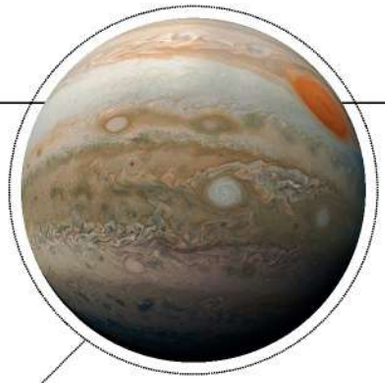
Jupiter's version of the northern lights has puzzled scientists because it doesn't behave like aurorae on Earth. Here the lights appear in a ring between 60 and 70 degrees north or south of the equator. Within that ring – an area known as the 'polar cap' – they don't appear. On Jupiter there is no 'polar cap', so aurorae continue all the way to the poles. This is due to a strange quirk of Jupiter's magnetic field. On Earth, the aurorae appear on closed field lines, which extend outwards from the planet before bending back again. Inside the 'polar cap' the field lines are open and there are no aurorae. But Jupiter has a mixture of open and closed field lines as you approach its poles, meaning the aurorae are still able to appear.



Another Jupiter

Little is known about how planets as large as Jupiter form, but a planet circling another star – and under the watchful eye of Hubble – could give us a lot of information. Known as PDS 70b, the planet orbits a very young orange dwarf 370 light years away in the southern constellation of Centaurus, which has two actively forming planets within its protoplanetary disc. PDS 70b, which orbits the star at the same distance as Uranus orbits our Sun, is already around five times the mass of Jupiter – and possibly twice as large – and at a mere 5 million years old should continue to form for a little while yet, though the rate at which it is accreting more material has dwindled.





EVOLUTION OF THE JOVIAN GIANT

- **Time:** 4.6 billion years ago
  Activity: The Solar System began to form from a cloud of gas and dust around a new star.
- **Time:** 4.596 billion years ago
  Activity: Jupiter and Saturn began to take shape.
- **Time:** 2400 BCE
  Activity: Babylonians tracked a full cycle of Jupiter's movement across the skies.
- **Time:** 270 BCE
  Activity: Jupiter was part of Aristarchus of Samos' heliocentric model of the Solar System.
- **Time:** 1610
  Activity: Galileo discovered the Galilean moons: Ganymede, Callisto, Io and Europa.
- **Time:** 3 December 1974
  Activity: Pioneer 11 passed within 42,500 kilometres (26,400 miles) of Jupiter's cloud tops.
- **Time:** 5 March 1979
  Activity: Voyager 1 performed a flyby of the gas giant planet.
- **Time:** 8 December 1995
  Activity: The Galileo probe entered Jupiter orbit.
- **Time:** 5 July 2016
  Activity: The Juno probe entered a polar orbit around the planet.

JUPITER BY NUMBERS

14x
Jupiter's magnetic field is 14 times stronger than Earth's and is the strongest in the Solar System except for sunspots

4th
Fourth-brightest object in the sky as seen from Earth

1665
Jupiter's Great Red Spot is a storm known to have existed since at least 1831, and maybe even since 1665

11.8
Years Jupiter takes to orbit the Sun

79
known moons circulate around Jupiter

5,000 kilometres
The thickness of Jupiter's atmosphere – the deepest in the Solar System

FUTURE PLANS FOR JUPITER

While Jupiter has been heavily photographed by missions such as Juno, which arrived at the planet in 2016, much scientific interest has now transferred to the planet's moons, which are thought to harbour subsurface liquid oceans and possibly even life. Europa, Ganymede and Callisto, three of the Galilean moons, would be the targets, but multiple missions have been cancelled due to lack of budget.

In 2024 NASA's Europa Clipper should launch, following up on studies from the Galileo probe and performing multiple flybys of Europa without orbiting it, using the gravity of nearby moons to change its course. The European Space Agency will send its Jupiter Icy Moons Explorer in April 2023 to study Ganymede, Callisto and Europa, evaluating their potential to support life. Other countries also have their eyes on the giant planet, with China's Gan De craft proposed for launch in 2029 and an unnamed Russian proposal to use a nuclear-powered tug to travel to the planet sometime after 2030.

Further into the future, Europa is seen as a potential site for human colonisation of the Solar System, as it is geologically stable and levels of radiation are low there. Low is a relative term, however, as unshielded colonists would receive 5.4 sieverts of radiation per day from Jupiter compared to 0.0024 sieverts per year on Earth. This is still enough to cause radiation poisoning.

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FOCUS ON

EARLIEST AURORA DOCUMENTED IN ANCIENT CHINESE TEXT

It's about 300 years older than the previous record holder

Reported by Laura Geggel

The earliest documented case of an aurora dates to the early 10th century BCE. Ancient Chinese text describes 'five-coloured light' witnessed in the northern part of the night sky towards the end of the reign of King Zhao, the fourth king of the Chinese Zhou dynasty. The exact dates of Zhao's reign aren't known, but it's likely that this event happened in either 977 or 957 BCE. Researchers discovered this colourful detail in the Bamboo Annals, a 4th-century BCE text written on bamboo slips that chronicled legendary and early Chinese history. Though scholars have been aware of the Bamboo Annals for some time, a fresh look at this particular section led to the realisation that it detailed what might be the earliest described aurorae, said study corresponding author Hisashi Hayakawa, an assistant professor at the Institute for Space-Earth Environmental Research at Nagoya University in Japan and a visiting scientist at the Rutherford Appleton Laboratory in the UK.

The newly analysed description likely refers to a geomagnetic storm, Hayakawa and study researcher Marinus Anthony van der Sluijs, an independent researcher based in Canada, reported in the study. Geomagnetic storms occur when the Sun – a 'breathing ball of gas' – belches out solar flares, ginormous bubbles of electrified gas that travel at high speeds through space.

Earth's magnetosphere usually protects the planet from the Sun's energetic charged particles, but sometimes these particles get through and cause magnetic disturbances, known as geomagnetic storms. Such storms can produce beautiful lights – oxygen glows green and red, whereas nitrogen gives off blue and purple light. Nowadays, the northern lights, or aurora borealis, occur at northern latitudes, while the southern lights, or aurora australis, happen at southern latitudes. But during the mid-10th century, Earth's north magnetic pole inclined towards the Eurasian continents – about 15 degrees

Aurorae glow different colours because the solar particles interact with different gases at different heights in Earth's atmosphere

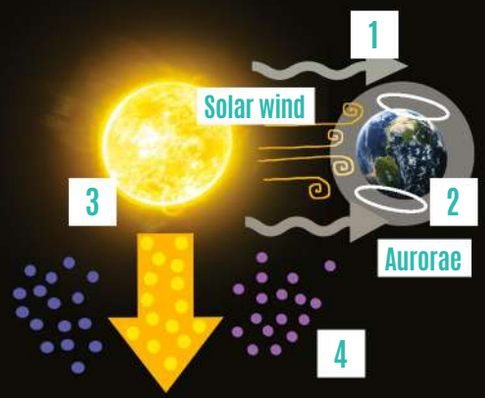
HOW AURORAE ARE MADE

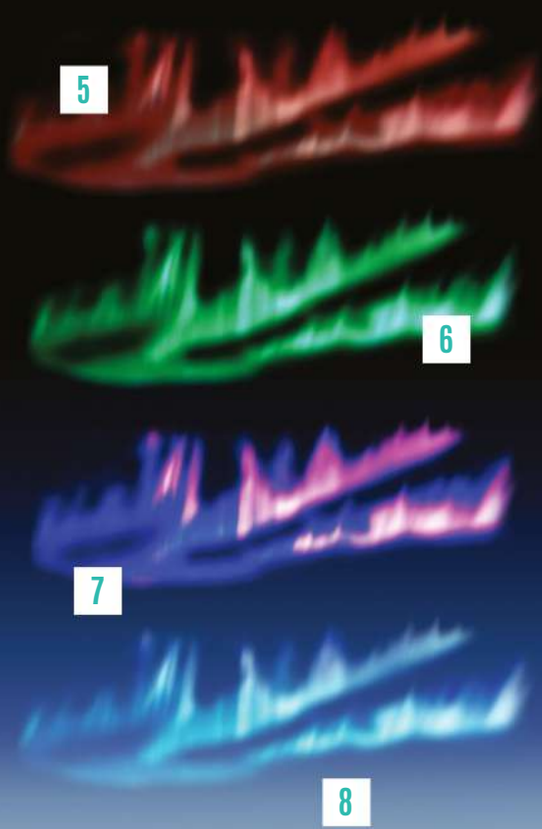
1 Solar wind
Activity on the Sun sends charged particles streaming out into space.

2 Magnetic field
The Earth's magnetic field funnels the particles of the solar wind towards our planet's poles.

3 Changing star
The Sun is a variable star, reaching its peak of activity every 11 years. During this solar maximum we expect to see more aurorae than at other times. The next maximum is in 2025.

4 Atmospheric collisions
As the charged solar particles collide with atoms of oxygen and nitrogen gas in Earth's atmosphere, they produce light.





5 Red lights
Red aurorae are created when solar particles strike atoms and molecules of oxygen above 241 kilometres (150 miles) in the atmosphere.

6 Green lights
Green aurorae are the most common. They're created when solar particles strike atoms and molecules of oxygen up to 241 kilometres (150 miles) high.

7 Purple lights
Purple aurorae are caused by solar particles interacting with atoms and molecules of nitrogen gas in the atmosphere at heights above 97 kilometres (60 miles).

8 Blue lights
Blue aurorae occur very low in the atmosphere – at heights of 97 kilometres (60 miles) or lower. They're rare, only seen during powerful displays.

closer to central China than it does today. As a result, it's possible that ancient people in central China – possibly as far south as 40 degrees latitude, or just north of Beijing – could have seen geomagnetic storms and the colourful lights they produced.

Mid-latitude aurorae can present multiple colours when they're bright enough, which could explain why the celestial event was noted as 'five-coloured light'. For example, in October 1847, a colourful auroral display was observed in the UK, Hayakawa said. According to a report near Cambridge, "a crown was formed near the magnetic zenith from which all the rays appeared to diverge; their colours were most splendid and of peculiar transparency, especially the red and green, the former being quite like carmine and the latter that of the pale emerald; the central part of this canopy, or that near the magnetic north, was of a very yellow colour, one streamer being quite like gold."

Hayakawa called this possible record-setting event a "candidate aurora," as the team doesn't have enough evidence to confirm an aurora. Previously, the oldest candidate aurorae were records inscribed by Assyrian astronomers on cuneiform tablets which dated to between 679 and 655 BCE, according to a 2019 study by Hayakawa and colleagues published in the *The Astrophysical Journal Letters*.

The latest finding took so long to be recognised for several reasons, Hayakawa noted. The original manuscript of the Bamboo Annals was lost, rediscovered in the 3rd century CE and then lost again during the Song dynasty. During the 16th century, a translation used the word 'comet' for the display, but the new study sets the record straight.

© Getty

UNLOCKING THE SECRETS OF THE ANTIKYTHERA MECHANISM

Scientists are closer to cracking a complex 2,000-year-old astronomical calculator after decades of painstaking work

Reported by David Crookes

In 1900, sponge diver Elias Stadiatis was in the waters off the coast of the Greek island of Antikythera when he made a startling discovery. What lay before him appeared to be rotting corpses and horses scattered over the seafloor amid the remains of a Greek shipwreck. After a team of divers were sent to take a look later that year, it didn't take long to work out what Stadiatis had seen: a treasure trove of bronze and marble statues, some of which dated back to the 4th century BCE. But the divers didn't know they had also recovered something even more remarkable.

An object roughly the size of a large book was discovered in the depths of the wreck in 1901. The following year, archaeologist Spyridon Stais happened to be looking at the book-sized lump and it began to crumble. As it did so, he could see a corroded piece of bronze embedded with precision gear wheels but most of the technology was obscured by corrosion. For a

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WHO BUILT THE ANTIKYTHERA MECHANISM?

No one knows who created the Antikythera mechanism, but many researchers believe Archimedes may have played a part. The ancient Greek mathematician, astronomer and inventor – the man who is said to have leapt out of his bath and run down the street naked shouting "Eureka!" after discovering the principle of buoyancy – lived around the time the device would have been made. One theory is that it was likely made after he died, based on his expertise. "Archimedes died about 212 BCE, when he was killed by a Roman soldier during the siege of Syracuse, and it's my belief he started the tradition of making these devices," Freeth says. "There's a description by the Roman politician Cicero of two machines made by Archimedes that showed the motion of the Sun, Moon and five planets. This is what the Antikythera mechanism does and there is evidence that there were more than one of these things around in antiquity. My belief is that Archimedes started the tradition of making these devices and they were picked up later by other people copying his designs."

The main surviving fragments are labelled A to G – this is an X-ray CT of the latter showing the inscriptions on the front cover

Some of the pieces have been very well preserved. Freeth says the mechanism would have come out of the sea in one piece, but broke up over the years

while it was simply a curiosity, and put on public display. Although some work was carried out, notably in 1905, by German philologist Albert Rehm, nobody went into great detail for some time. Still, Rehm made some interesting discoveries such as the inscription of the numbers 19, 76 and 223. And he became the first to propose it was an astronomical calculator since those numbers represented Moon-Sun cycles.

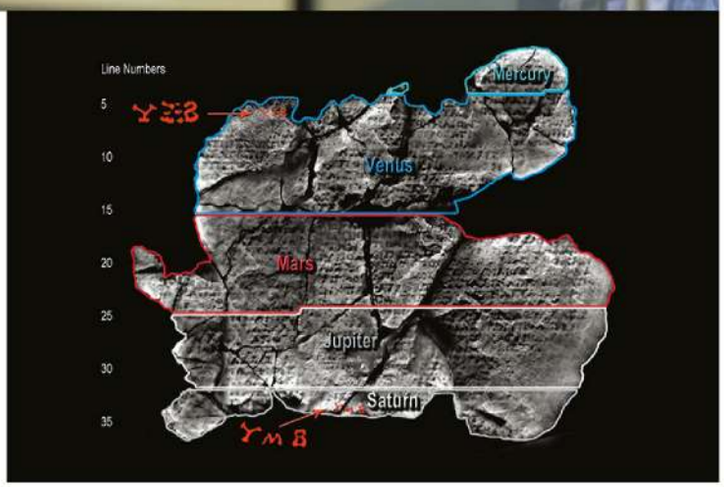
Babylonian astronomers had predicted eclipses of the Sun and the Moon based on the Saros cycle – a period of 223 lunar months. From the late 6th century BCE, they also applied what became known as the Metonic cycle, a 19-year period marking the recurrence of the lunar phases. Greek astronomer Kallippos improved on this with the 76-year Kallippic cycle in 330 BCE. Such figures appeared to show the device had been used to predict astronomical events, yet decades passed before more serious work was carried out.

In 1958, British physicist and science historian Derek J. de Solla Price began to look at the mechanism in greater detail at the museum in Athens. He embarked on a near-20-year study that resulted in a paper called *Gears from the Greeks* in 1974. By now, however, the mechanism was in 82 fragments, so anyone wanting to get to grips with it would, in effect, be working with an ancient jigsaw puzzle without the benefit of a finished image. What's more, a good chunk of it was – and remains – missing. "Only a third of the mechanism survives and that makes research difficult," explains Professor Tony Freeth, a mathematician and award-winning filmmaker who has also become fascinated by what he calls "an extraordinary device". Price called it the Antikythera mechanism, a name that stuck, and it appeared it could display celestial time. He said there were hands for the Sun, Moon and five known planets: Mercury, Venus, Mars, Jupiter and Saturn. It appeared it could predict astronomical phenomena and calculate dates with the turn of a hand crank linked to a set of gears. What's more, it could be easily carried around given it was little more than the size of a shoebox.

Mindful of not causing further damage, Price was careful in his examination of the device. "He carried out some X-rays because it's the only way to look at the gearing structure inside in a non-destructive way," explains Freeth. "It was a good-quality X-ray but it was two-dimensional. Everything was overlapping everything else in the structure, making it harder to work out what was happening." Even so, Price was able to get enough of an insight to prove the device really was remarkable, and appeared to be unique. Nobody had ever known something with such a sophisticated gearing system having been made at the time – it's at least as old as the shipwreck, which dates to between 60 and 70 BCE. In fact, to put it into perspective, there is still no evidence of anything as complex as this device having been made for a further 1,000 years.

Price's first breakthrough related to the number of gears. The X-ray scans, carried out with Greek radiologist Charalambos Karakalos, found 27 distinct gears in the largest fragment and a further three in a trio of smaller ones. Price also noted that the linked gears could calculate the average position of the Moon on any specific date.

Tony Freeth became interested in the Antikythera mechanism when he was approached by a professor of astronomy to make a film about it



As Freeth explains, Price found a main wheel drive on the front of the mechanism. It began with a 38-tooth gear driving a 127-tooth gear. This would allow the device to work out the repeating pattern of the Moon around the Earth as recorded by the Babylonians. The Metonic cycle of 19 years contains 254 sidereal months, which are shorter than a lunar month and represent the time needed for the Moon to return to the same place against the background of stars. The 38 teeth got around the problem of a 19-tooth gear being too small while the 127-tooth gear (half of 254) ensured a larger gear wasn't needed.

This was proven by another important researcher, physicist and historian Michael Wright, a former curator of mechanical engineering at the Science Museum in London. Along with Australian professor of computer science Alan G. Bromley, he carried out a second X-ray in 1990. "They used an X-ray technique called linear tomography, which had been used in the Second World War to locate shrapnel fragments in the human body," Freeth explains.

The pair took 700 radiographs of the device and this enabled a fully working replica to be created which was unveiled in 2002. Based on a theorised arrangement of the internal gears and their number of teeth, it also included a front display showing the 19-year sequence of 235 months. It had indicators for the Sun and Moon as well as the five observed major planets. It was leaps ahead of Price's work which Wright had considered to be incomplete. "Wright made some important progress," says Freeth. And yet more key insights were to come. Freeth and a team including Alexander Jones of the Institute for the Study of the Ancient World, spent five years pushing for a fresh

ANTIKYTHERA MECHANISM BY NUMBERS

2,200
Rough age in years

122
Years since it was discovered

1905
The year Albert Rehm realised it was significant

FIVE
Number of planets included

46
Depth, in metres, of the seafloor where it was found

30
Number of surviving bronze gears

69
Total number of gears proposed

3,400
Number of characters found on the device

12
Zodiac signs on the front

205 BCE
Year the device was likely made

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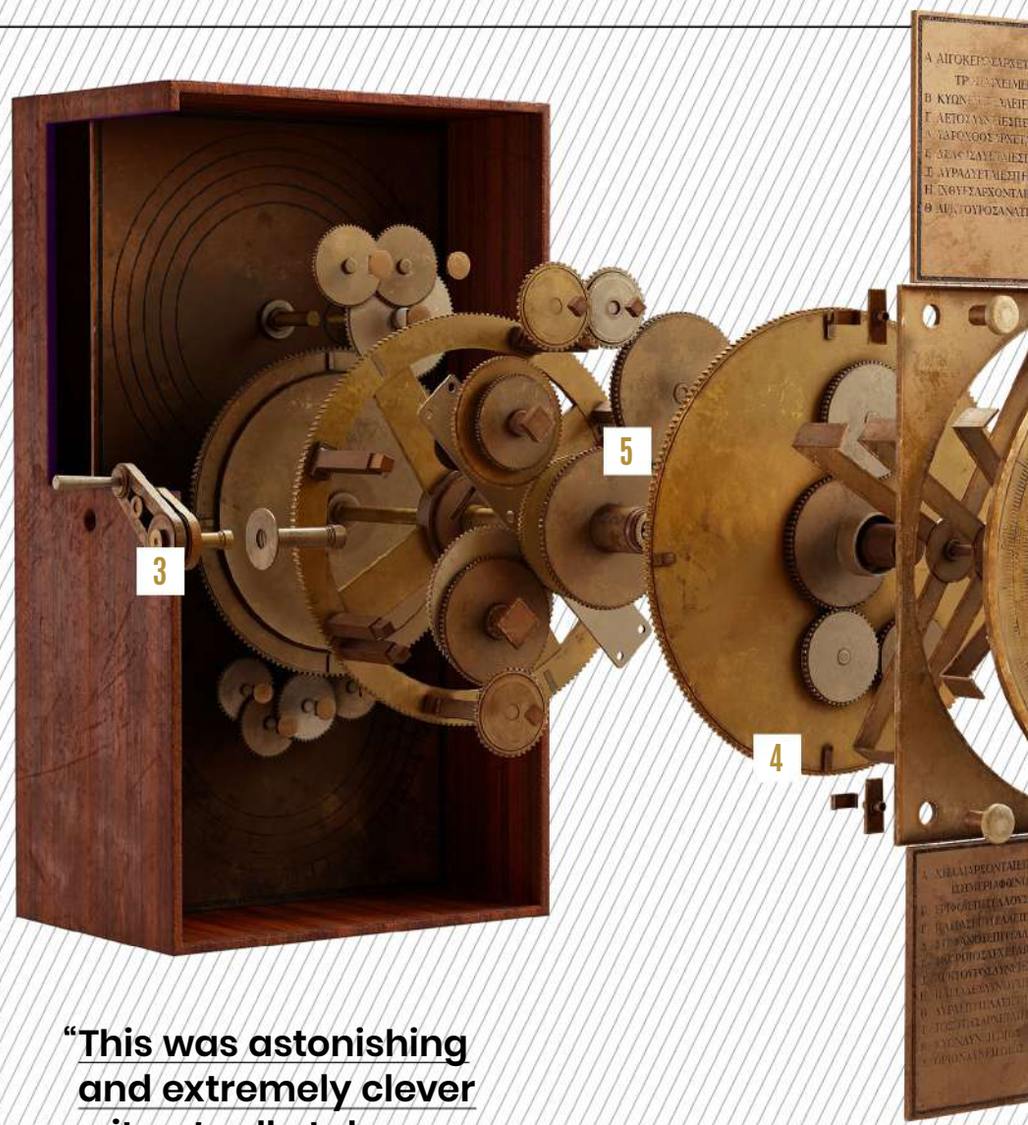
HOW THE ANTIKYTHERA MECHANISM WORKED

Scientists have created a computer model showing the inner workings of this mysterious device



1 The front plate
The front had the zodiac dial split into 12 constellations, showing the positions of the Sun and Moon, with the planetary positions shown using coloured beads.

2 Prominent inscriptions
Inscriptions on the front plate described the times when important stars would rise and set throughout the year.

3 The crank
By turning the crank on the side, the user caused the gears inside to turn. These moved the pointers located on the front and back of the device.

4 Primary gear
On the back of the primary gear was a series of smaller gears, activated when the crank was turned. Some of them formed the lunar gear train.

5 The Instruments
Gears at the back of the device include the Metonic gear train and the eclipse gear train, which calculates the month in the Saros cycle.

6 The back plate
As well as displaying the Metonic month and the months when eclipses would occur, the device also showed the years when Olympic Games and other festivals would be held.

"This was astonishing and extremely clever – it actually takes your breath away"
Tony Freeth

scan, eventually triumphing in 2005. "I persuaded a UK company called X-Tek Systems to develop a prototype machine that could take images using microfocus X-ray computed tomography scans."

The insights gained from this study were startling. "We found the device predicted eclipses," Freeth says. Indeed, the scans showed there was a 223-tooth gear at the rear of the mechanism that turned a pointer around a dial to predict the months that would feature an eclipse. What's more, it was possible to see the gears observed by Wright in greater detail, showing they were epicyclically mounted on the 223-tooth gear. They also calculated the Moon's variable motion. "This was astonishing and extremely clever – it actually takes your breath away," Freeth continues of the device's accomplishment. "The problem with the Moon's motion is that it is complicated and difficult, but the ancient Greeks had a theory to predict it and this was built into the mechanism." The X-ray data from 2005 also revealed thousands of text characters hidden inside the fragments. Many of them were inscribed on the back cover of the Antikythera mechanism, describing the cosmos display. Freeth says the writing was akin to a user manual.

They weren't easy to decipher, though. "To read inscriptions from the X-ray CT data, we had to look at about 60 CT slices, going up and down to try and determine what a character was," says Freeth. Yet perseverance won and such breakthroughs allowed a better understanding of the gearing system at the front of the device. It also affirmed that they were dealing with a highly complex piece of kit. The planets, it seemed, were indicated by marker beads and they moved in a concentric system of rings. This was

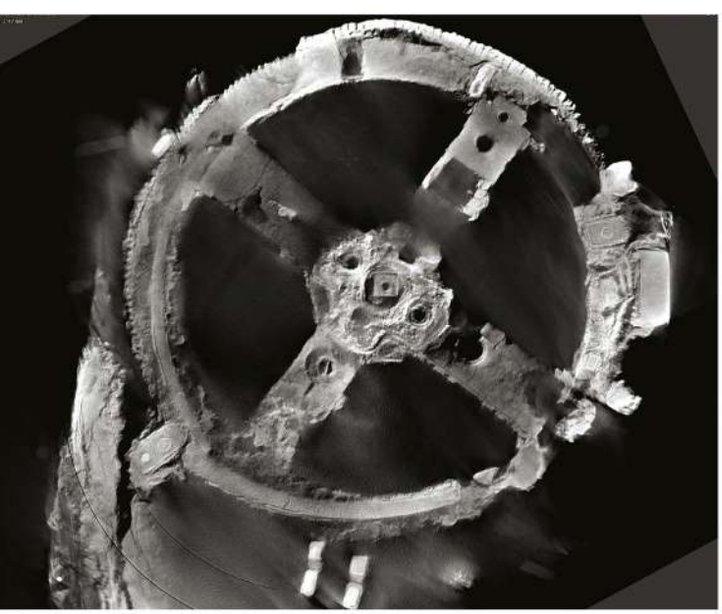
Fragment A shows the largest gear in the mechanism. This X-ray CT shows it in great detail, giving researchers a key piece to their puzzle

PhD candidate David Higgon has a background in watch and clock repair; he's using his skills to physically replicate the device

based on epicyclic models for the planets that, Freeth says, were almost certainly introduced by the Greek astronomer Apollonius of Perga in the late 3rd or early 2nd century BCE. Epicyclic models explained an observation originally made by the Babylonians and continued by ancient Greek astronomers: that the Moon moved faster at perigee and slower at apogee. The Greeks didn't know about elliptical orbits at the time and they saw the planets moving from west to east in the night sky, occasionally stopping and reversing their motion. By having a circle on top of another circle, it was possible to compensate for this.

Slowly but surely, a big pot of information was coming to the boil and the ingredients were giving greater clues than ever about how the Antikythera mechanism worked. Freeth headed the University College London Antikythera Research Team, which attempted to recreate the front mechanism. They knew it had to match the inscription of how the Sun and planets were displayed. Critical to this were two numbers discovered by Jones via X-ray CT scans on the front cover: 462 and 442. These were written in two of the five cover sections dedicated to the planets, and they related to Venus and Saturn.

Again Freeth was astonished. The numbers represented the cycles of the two planets in years yet there was no evidence the ancient Greeks had knowledge of this. Assuming this was the case, the original makers of the device presumably had worked it out. But how? The team used an ancient mathematical method described by the ancient Greek philosopher Parmenides of Elea. By applying this method, the researchers also recovered the cycles of the other planets where the evidence was missing and, having identified the planetary cycles built into the mechanism, it became possible to work out how the device operated. Two recovered fragments from the wreckage – since labelled A and D – could be matched to a mechanism for Venus, allowing its 462-year planetary period to be modelled. The discovery of a 63-tooth gear inside Fragment D also proved crucial, with Freeth saying that 63 shares the prime factors three and seven with 462.



Such breakthroughs led to the creation of innovative mechanisms for all the planets, enabling the calculation of astronomical cycles using the lowest possible number of gears. They could create a computer model for a mechanism of overlapping gears that fitted a compartment barely 2.5 centimetres (one inch) deep. Best of all, it seemed to work. By recreating the gears and rotating dial, the plants, Sun and Moon could be seen to move across an ancient map of the stars on the front of the Antikythera mechanism along with the phases of the Moon.

Of course, a lot has changed since the ancient Greeks created this amazing gadget. But what the Antikythera mechanism shows first and foremost is just how advanced ancient Greeks really were. So much so that researchers, despite knowing much more about the Antikythera mechanism now, are still far from declaring the puzzle solved. There are so many pieces missing and much still to discover, meaning it's likely to occupy minds for some time to come.

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

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FOCUS ON

HUBBLE SPOTS STAR THAT SURVIVED A VIOLENT EXPLOSION

NASA's most iconic space telescope has uncovered an object that survived the violent death of its companion

Reported by Samantha Mathewson

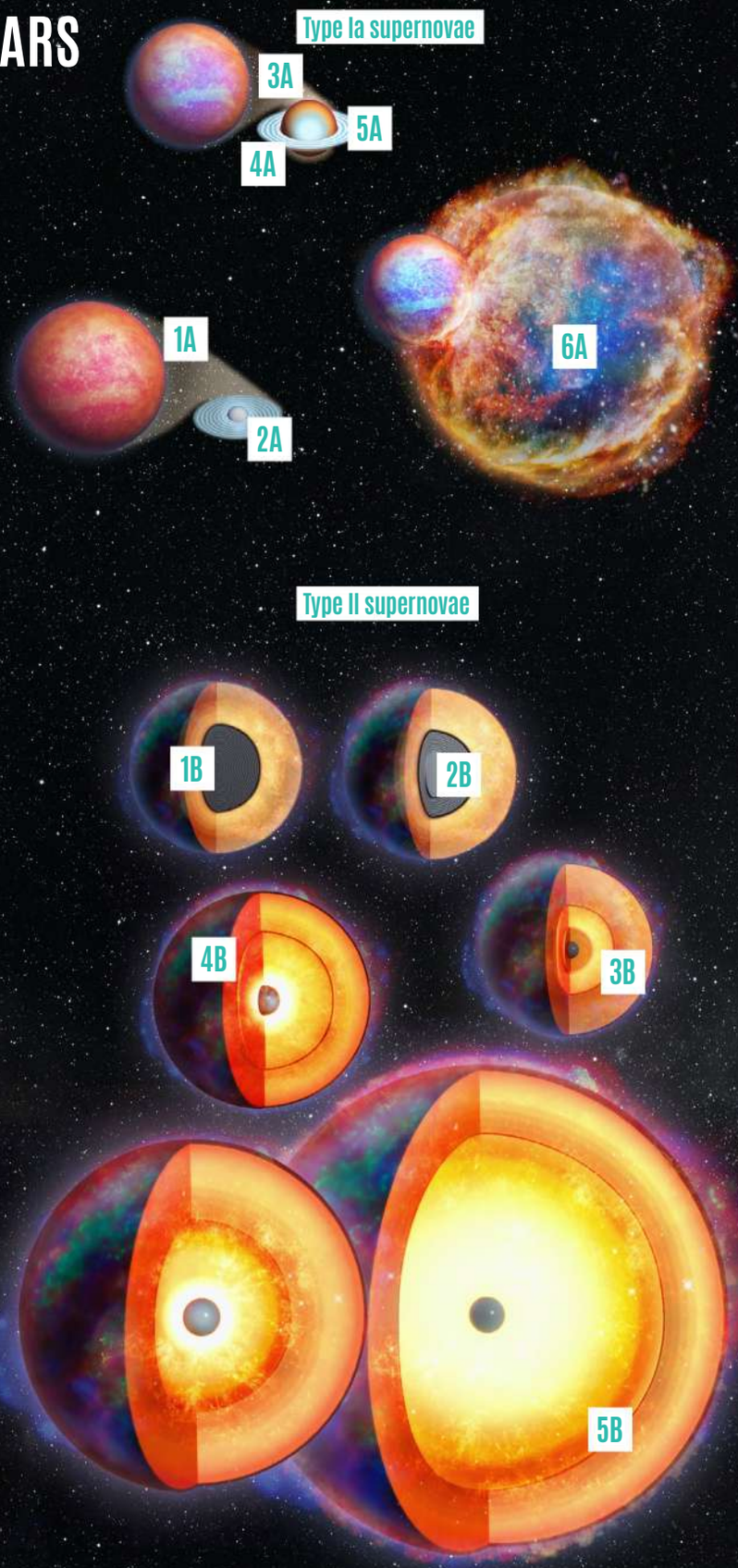
When a massive star reaches the end of its life, it explodes in a brilliant burst of light known as a supernova. This bright explosion can briefly outshine entire galaxies, which is how the star's surviving partner remained hidden from view. Using Hubble's Wide Field Camera 3, researchers were able to study the supernova SN 2013ge in ultraviolet light. The scientists found that while the light from the bright stellar explosion has been fading since 2016, another nearby source of ultraviolet light has maintained its brightness over time, suggesting SN 2013ge has a surviving binary companion.

"This was the moment we had been waiting for, finally seeing the evidence for a binary system progenitor of a fully stripped supernova," Ori Fox, lead investigator on the Hubble research program, said. "The goal is to move this area of study from theory to working with data and seeing what these systems really look like." Using the Hubble data, astronomers were able to identify the signature of various elements in the supernova explosion. Strangely, no hydrogen was detected in the region of SN 2013ge, leaving scientists to guess at how the gas might have been stripped away before the explosion occurred.

The observations shed new light on the nature of massive stars in binary systems. Observations of SN 2013ge also help explain how some stars are stripped of their hydrogen presupernova, which in this case is the result of an unseen stellar companion siphoning gas from its partner before it explodes. "Many different lines of evidence have told us that stripped supernovae are likely formed in binaries, but we had yet to actually see the companion," Maria Drout, an astronomer from the University of Toronto, said. "So much of studying cosmic explosions is like forensic science – searching for clues and seeing what theories match," Drout added. "Thanks to Hubble, we are able to see this directly."

Astronomers can now use SN 2013ge's surviving companion to better understand the characteristics of the star that exploded. And the researchers will be able to track the surviving star's evolution. Depending on the distance between the original companion stars, the surviving partner will either be flung out of the system – which could help explain why solitary supernovae are observed across the universe – or continue orbiting its companion before merging to create gravitational waves. However, such an event would not occur for a billion years, the researchers said. "Understanding the life cycle of massive stars is particularly important to us because all heavy elements are forged in their cores and through their supernovae," Alex Filippenko, coauthor of the study and an astronomer at the University of California, Berkeley, said. "Those elements make up much of the observable universe, including life as we know it."

HOW DO STARS EXPLODE?



Type Ia supernovae

1A Finding the right stars

These occur when a white dwarf is found in a binary pair with another star.

2A Matter transfer

Occasionally the two stars will orbit close enough that matter will transfer from the companion onto the white dwarf.

3A Squeezing down

This accretion of matter adds extra mass. The additional gravitational forces compress the already highly pressurised core of the white dwarf.

4A A star reborn

The dying star comes to life again and undergoes fusion in its centre.

5A Limited gains

White dwarfs can only get so massive through accretion, about 1.4 times the mass of our Sun.

6A Outward pressure

The star can no longer expand. Expansive forces build, creating a violent supernova.

Type II supernovae

1B Out of gas

Supergiants eventually run out of fuel, the burning of which prevents them collapsing.

2B Elemental onion

Heavier elements build up at the star's centre, which becomes layered, with lighter elements towards the outside.

3B Resistance is futile

This act of resistance holds until the star's innermost core is composed of iron, which won't fuse. Gravity wins and the star's outer layers collapse inwards.

4B Burning fuels

For stars this size, their mass and compressional forces at the core allow them to fuse heavier elements in order to maintain outward pressure.

5B Shock wave rebound

This inward implosion bounces back off the core as a rebounding shock wave that blows the whole atmospheric envelope off the star in a supernova.

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INSIDE AREA 51

The region is synonymous with tales of UFOs, government cover-ups and testing alien technology

Reported by Robert Lea

Located at Groom Lake in the middle of the barren desert of southern Nevada, Area 51 is a US Air Force installation that has become infamous for a speculated connection with unidentified flying objects (UFOs). Conspiracy theories surrounding the base suggest that it's used for the testing of alien technology recovered from supposed crash sites, like the one in Roswell, New Mexico. This has been fuelled by the fact that the base was a secret for many years and is still inaccessible to the general public. As a result, this innocuous-looking military installation has become an intrinsic part of modern mythology and urban legends of the 20th century, with a large influence on media and pop culture.

WHERE IS AREA 51 AND HOW BIG IS IT?

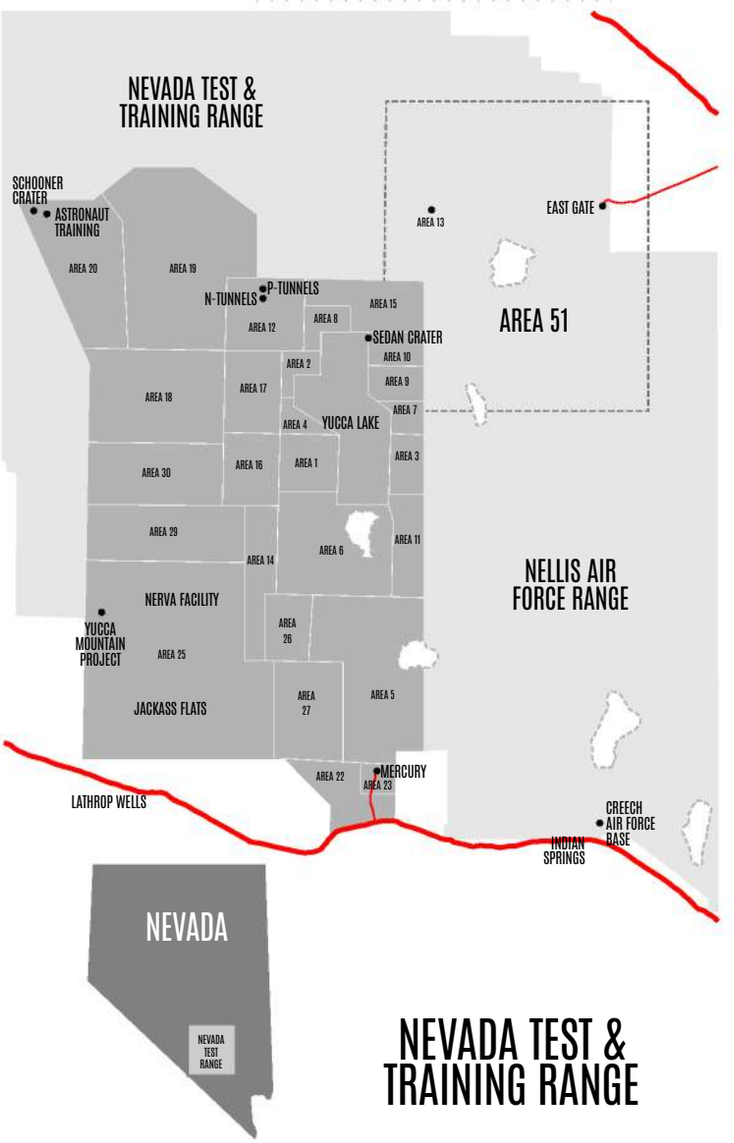
Area 51 is located 120 miles (200 kilometres) northwest of Las Vegas, near the small towns of Rachel and Hiko. The name Area 51 seems to come from the designation the base had on Atomic Energy Commission maps, with this name sticking in the mind of the public but mostly unused by the military. Established in 1955 as part of the Nevada Test and Training Range complex, the area was also given the name 'Paradise Ranch' in an attempt by aerospace company Lockheed, now Lockheed Martin, to draw employees to the base.

Today the base and the wider Nevada Test and Training Range complex are part of the Nevada National Security Site (NNSS), with the Central Intelligence Agency (CIA) referring to it as the Groom Lake and Homey Airport. Though satellite imagery of the site had been restricted, since 2018 the base has been visible on Google Maps.

Benjamin Radford is an American folklorist, writer, investigator and sceptic who's authored more than 20 books, including *Scientific Paranormal Investigation: How to Solve Unexplained Mysteries*; *Tracking the Chupacabra: The Vampire Beast in Fact, Fiction and Folklore* and *Mysterious New Mexico: Miracles, Magic and Monsters in the Land of Enchantment*. He's also deputy editor of *Skeptical Inquirer* magazine and has written several articles regarding the conspiracy theories surrounding Area 51.

"The base itself is fairly small, but the restricted area around it is over 90,000 acres – partly to prevent prying eyes and partly because they need to test classified aircraft," Radford says. "It's mostly conspiracy theorists and the media who call it Area 51. To the US government it's simply the Nevada Test and Training Range, part of Edwards Air Force Base."

"This innocuous-looking military installation has become an intrinsic part of modern mythology"



© Getty

WHAT IS IT USED FOR?

The US military finally acknowledged the existence of Area 51 in 2013 after a formerly classified CIA document detailing the history of the U-2 spy plane was obtained by the National Security Archive at George Washington University. But that acknowledgment doesn't mean that a visit to the base is advisable. Radford says that there are still legitimate government and military reasons for keeping the base's activities secret. "The military classifies Area 51 as a Military Operating Area. On the ground you'll encounter stern signs and armed guards patrolling the fenced perimeters guarded by buried motion sensors, cameras, guards and so on – plus signs warning that deadly force is authorised," Radford explains. "The borders of Area 51 are not fenced but are marked with orange poles and warning signs." Such signs tell visitors that photos aren't allowed and that trespassing on the property will result in a fine, he adds.

Originally used as a testing site for the U-2 spy plane, the base would go on to be used for the testing of other well-known aircraft such as the A-12, the SR-71 Blackbird and the F-117 Nighthawk stealth fighter.

HOW AREA 51 BECAME ASSOCIATED WITH UFOS

The testing of new and secretive military aircraft is likely responsible for much of the connection between Area 51 and UFOs, especially when considering that the term UFO doesn't directly refer to alien spacecraft, despite how it's often perceived in pop culture. "It's true that strange lights and aircraft can sometimes be spotted in the area, so it's an obvious leap to UFOs, but new aircraft might look identical," Radford explains. "The basic, flawed premise behind the Area 51 mythology can be boiled down to this: the government won't reveal what's going on there, so it must be something amazingly secret."

What we call Area 51, he adds, is only one of many military bases, national laboratories and government scientific research centres across the country that deal with classified – even top-secret – information, and where workers and visitors need security clearances. "There's no reason to think that anything UFO-related is going on," Radford says.

Aside from the sightings of strange craft, Area 51 mythology was enforced in 1989 when a man named Robert Lazar claimed that he worked on extraterrestrial technology inside the base. Lazar told Las Vegas television reporter George Knapp that he had viewed autopsy photographs of aliens inside Area 51 and that the US government used the facility to examine recovered alien spacecraft. Lazar himself was discredited, but his claims resulted in numerous government conspiracy theories, most of which involve extraterrestrial life.

"A lot of the legend has been fuelled by hoaxers like Robert Lazar, who appeared in the 1980s telling a story to TV stations that he worked there and saw alien bodies and crashed flying saucers first-hand," Radford recalls. "It got a lot of attention, but it was later revealed that he fabricated not only his employment at Nellis [Air Force Base in southern Nevada] but indeed his entire background. Almost none of what he said was true."

Lazar had set the ball rolling, however. No matter how fallacious the rumours of alien technology and Area 51 were, the connection was cemented into the public consciousness and pop culture.

> "The connection was cemented into the public consciousness and pop culture"

AREA 51 IN POP CULTURE

Aside from the host of documentaries made about Lazar and the Area 51 UFO connection, the base has become a popular location in more overtly fictional movies and TV shows. Perhaps one of the most widely viewed interpretations of Area 51 appeared in the 1996 blockbuster *Independence Day,* starring Will Smith. In the Roland Emmerich-directed movie, the base plays a crucial role in defeating an invading alien menace.

On the small screen, Area 51 was host to a special prisoner in a 2011 episode of *Doctor Who.* The time-travelling Doctor was held captive at the base during the sixth-season episode *Day of the Moon.* And given the fact that it's a show based on aliens, conspiracy theories and government cover-ups, it's little wonder that Area 51 eventually made it onto *The X-Files.* In the 1998 season-six episode entitled *Dreamland* – also an early name given to the base – Mulder and Scully witness the flight of a mysterious craft at the facility.

Area 51 became part of the Marvel Cinematic Universe in season seven of *Agents of Shield,* appearing in two episodes of the show and getting a mention in a third. The base was also mentioned by *Spider-Man* antagonist J. Jonah Jameson's publication The Daily Bugle in a series of video packages as part of the viral marketing campaign for the film *Spider-Man: No Way Home* at the end of 2021.

The Daily Bugle reports referenced a 'failed raid' on Area 51 by people who aimed to discover evidence of alien life. More than a million people were supposed to conduct the raid, but only a handful actually showed up – a clear case of art imitating life.

The SR-71 Blackbird was one craft tested at the US Air Force site

Agents Fox Mulder and Dana Scully, protagonists of *The X-Files* series

© Getty

IS THE TRUTH REALLY OUT THERE?

Former CIA operative Ben Smith investigated the crash which took place in Roswell in 1947 for a television documentary called *Roswell: The First Witness*. He spoke to the grandchildren of Major Jesse Marcel, the person sent to the crash site to gather debris for analysis. He also visited the site with aviation crash experts, studied a journal found among Marcel's possessions for clues and spoke to other witnesses. Was Marcel right? Was the evidence gathered that day really not of this Earth?

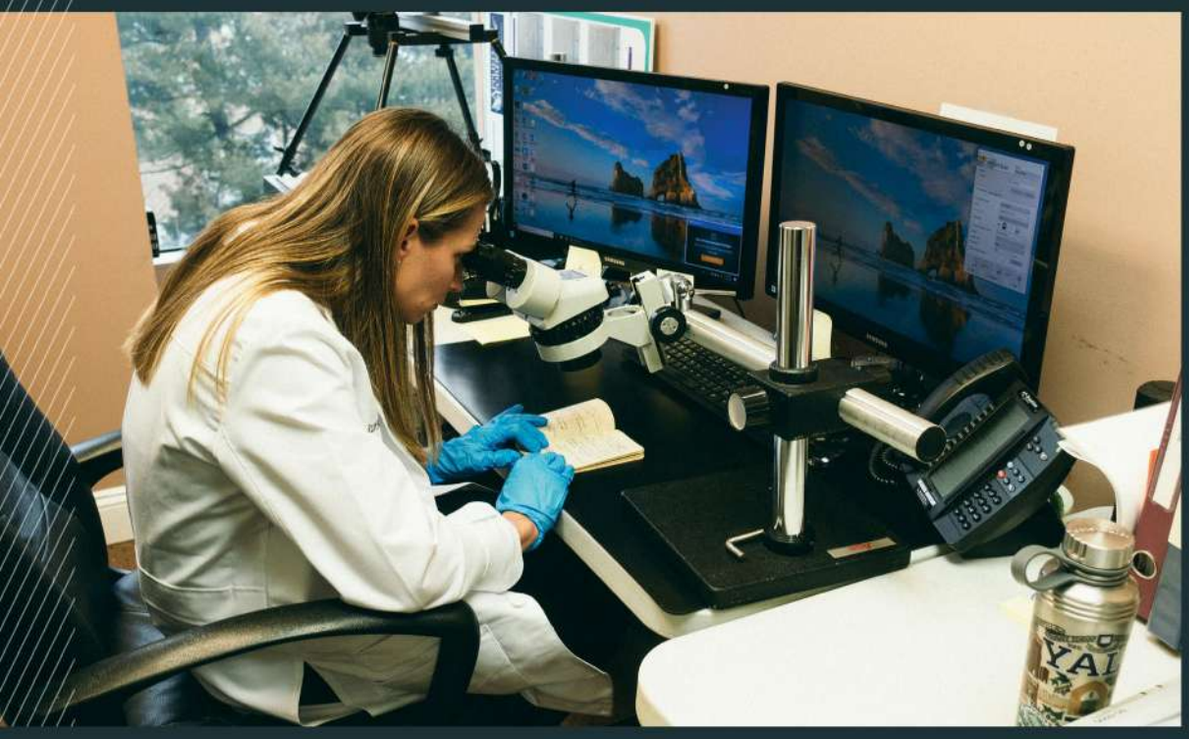
Before you began investigating, were you sceptical about what happened that day in 1947?
I think my initial attitude was one of not scepticism, but healthy doubt. Being a member of government, having formerly worked for the CIA, I'd seen how information is compartmented. The priorities, from a national security standpoint, didn't really seem to align with aliens and the possibility of a huge, vast conspiracy. I've been involved with some pretty expensive operations and I had never heard about the need to cover something like this up. But maybe I was so low or unimportant that I didn't know everything that was going on at the CIA.

In the series you heard Marcel's version of events, not only through his family, but via tape and video recordings from past interviews. Do you believe what he was saying was true?
Listening to the recordings, talking to body language experts, getting to know Marcel's family and seeing the fruits of his personality and his character manifested in his children and his grandchildren, I did believe his account in so much that he believed it. I don't think he was lying, but I still found discrepancies.

We had Jesse saying that what he found was like balsa wood, but his son calling it an i-beam, so there are already witnesses with different accounts. And then you stack on properties of what was found – like 'memory metal' and 'unbreakable' – and I couldn't find any direct evidence that these claims were from Jesse Marcel's mouth. That was always a tricky part. What came first: the idea of memory metal or the witness accounts?

How trustworthy are personal accounts?
Personal accounts are always tricky, even in the intelligence world, especially when you have individuals claiming they have access to super-important information about enemy plans or a terrorist attack or what have you. You always have to take that with a grain of salt. You always have to investigate the person's motivations, their mental stability, because the last thing you want to do is sell fiction, or something not true, that could result in something terrible, like a war, based on false information. There's a tricky aspect to this, and that's part of the challenge of dealing with something 70 years old. I really tried to do my best to cut through and focus on hard evidence, then weigh people's accounts with what we could find.

There was a lot of focus in the documentary on a journal found among Marcel's possessions. Why was it seen as a vital piece of evidence?
There are two factors: one, the words were written in an Army handbook around the same time of Roswell, and two, it was among the very few documents Marcel passed to his children. He handed over his military records, his medals and this journal to his son, and then later his grandchildren. I think as a primary document,



< Jennifer Naso forensically examines an intriguing journal found in Marcel's possessions to see if it dates to 1947 and could potentially hold clues

or a firsthand account, it's really the first potential evidence we have of what really happened at Roswell outside of some of the oral histories, and the question is why was this diary so important to him. Reading it, it seems to be a series of random musings, so we wanted to see if there was a code in there. As we saw in the series, codebreaking didn't work out. But there's still a possibility that the person who wrote it – and we found it wasn't Marcel himself – would remember, if they're still alive. I hope I get the chance to keep following up on it.

The government says the object that crashed was a high-altitude balloon used as part of a mission to spy on Russian atomic tests called Project Mogul. Did your investigation reach the same conclusion?
That was the confusing part. We took a safety aviation crash expert to the site, and he at first ruled out the idea of a Mogul balloon – said it was just impossible for it to have been a balloon. We had another witness scheduled who has pretty convincing research that suggested it definitely wasn't a balloon. I'm not convinced by the excuse.

Were there any people that you wanted to speak to as part of the investigation?
We had more witnesses lined up, but we kind of got hit with the pandemic and travel and health and safety issues, so we didn't get to do all that we wanted to. I would love to have interviewed some of the original researchers like Stan Friedman, who was one of the first to propose the theory that this was a government cover-up. I would have liked to ask the hard questions about who was the first person to say 'memory metal'. Who used that? Where did it come from? I was able to get time with folks like researcher Don Schmidt, who interviewed a lot of the original witnesses, but even he couldn't give those kinds of answers.

So you'd like to continue the investigation?
Oh, absolutely. I don't think I'm done, and it's definitely made me more curious. I think there were a number of leads that we generated that I want to follow up on, and it's still an open question in my mind. Until I feel like I have enough to form at least not a foolproof opinion, but something I could tell viewers that I think happened, then I won't be satisfied. My investigation so far hasn't convinced me either way, and I need hard evidence, but I think we got closer than others in looking for a conclusion.

THE AREA 51 MOVEMENT

In 2019, what started as a prank on social media almost got very out of hand when 3.5 million people expressed interest in attending an event organised by 20-year-old Matty Roberts, a student from Bakersfield, California. The name of the tongue-in-cheek Facebook event was 'Storm Area 51, They Can't Stop All of Us'. As the name suggests, the supposed plan was to charge at the base in large enough numbers to overwhelm security. The aim was to uncover putative secrets like alien technology and secretive research.

In the end, an estimated 6,000 people made it to the low-key summer event, partaking in some activities like hatchet-throwing and drinking limited-edition alien-themed Bud Light beer. Area 51's light security was not challenged, however. "It began as a joke, but some people took it seriously and began planning to actually, well, it's not clear what, but hang out near the entrance and have fun," Radford said. "The tiny town of Rachel braced for huge crowds and a music festival that never happened. It was a huge fiasco, a smaller-scale Fyre Festival for the alien crowd."

"The aim was to uncover putative secrets like alien technology and secretive research"

▲ Rachel, Nevada, is one of the closest towns to Area 51

▼ Conspiracy theorists have long been demanding answers from the government

© Getty

INSTANT EXPERT

HOW ARE AURORAE FORMED ON OTHER PLANETS?

The northern and southern lights occur when the solar wind affects our atmosphere, but this can happen on other worlds too

The shimmering northern lights, or aurora borealis, are a natural light show that occurs in a loop around the poles. The southern version is known as aurora australis. Aurorae occur when charged particles emanating from the Sun – the solar wind – crash into the upper atmosphere. A mixture of electrons, protons and helium nuclei, they lose energy as they collide with atmospheric gas molecules. These gas molecules become ionised – some of their electrons are pulled away – and the gases form a glowing plasma. The gas mix governs the colours we see. Red is generated by low concentrations of oxygen at high altitudes. This changes to green as oxygen density increases, with blue generated by nitrogen. Pink, yellow and orange have all been observed, presumably due to the layering of different amounts of red, green and blue. Intriguingly, because our eyes construct our colour perception from red, green and blue-sensing cells, aurorae could form any colour at all depending on the combination of the primary gas colours. Aurorae are clustered around the poles because Earth's magnetic field dips into the surface. There, particles are repelled from lower latitudes and funnelled into the atmosphere in loops around both poles. But these bands can grow with strong solar storms, occasionally bringing aurora as far south as southern Britain and northern France.

Other planets in the Solar System have varying combinations of magnetic fields and atmospheres, but we've found aurorae there too. The most spectacular display is on Jupiter, with 14 times the magnetic field of Earth. As well as the solar wind it has its moon Io, the most volcanically active body in the Solar System, cutting through its magnetic field while spewing out more gases. Indeed, aurorae have been observed around Io, Europa and Ganymede because of the complex interactions with Jupiter.

Saturn's aurorae have been captured by a number of spacecraft, even from the Hubble Space Telescope in Earth orbit, but the energy characteristics and gases involved produce ultraviolet light that would be invisible to humans. Despite Mars' limited magnetic field and atmosphere, Martian aurorae have been observed by the European Mars Express probe, clustered around magnetic variations in the crust.

Most curious of all, however, are the Venusian aurorae. Venus has no magnetic field, but Mars Express' Venusian twin found magnetic effects produced by the solar wind interacting with the charged outer layer of the atmosphere. This seems to produce random patches of light, as they are not fixed to magnetic poles.

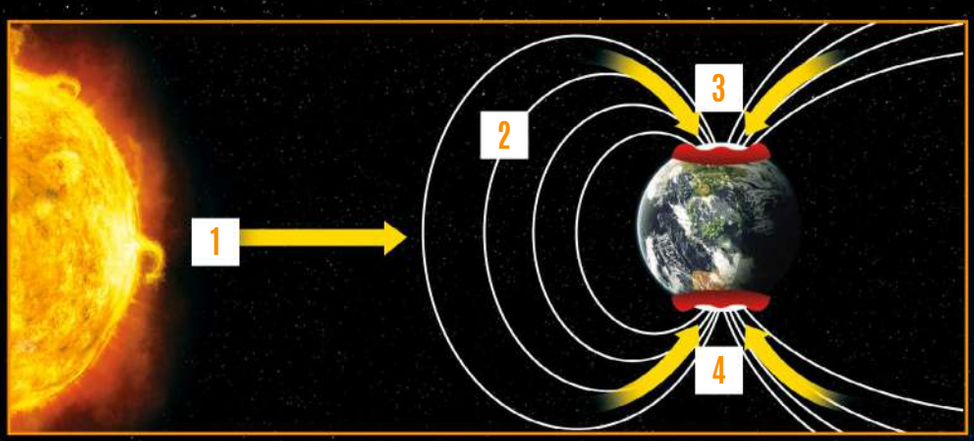
BIO
ROBIN HAGUE
Hague is a science writer, focusing on space and physics. He is the current head of launch at Skyrora, coordinating launch opportunities for Skyrora's vehicles and liaising with UK launch regulators.

1 Solar wind
A mixture of free electrons, protons and helium nuclei stream out of the Sun constantly, increasing in density with solar storms.

2 Earth's magnetic field
Earth's magnetic field is believed to be generated by the molten iron circulating around the core.

3 Magnetic poles
Because the field dips into our planet at the poles, charged particles are funnelled into the atmosphere there.

4 Ionisation
As solar wind particles hit gas molecules on Earth, they dump their energy into them, forming the glowing auroral plasma.



1 Auroral noise
Sounds have been reported along with aurorae; it's believed this may be due to the electric field causing charged molecules in the lower atmosphere to vibrate.

2 Induced currents
Aurorae can induce electrical currents as they interact with the atmosphere. It was reported in the 19th century that telegraph networks could even draw power from them.

3 Colour layers
Diffuse oxygen produces red light in the highest aurorae, changing to green as density increases, with nitrogen generating blue light lower down.

4 Altitude
Aurorae occur between 90 and 150 kilometres (56 and 93 miles) altitude, straddling the boundary of space but below the orbit of the International Space Station.

"Other planets have varying combinations of magnetic fields and atmospheres, but we've found aurorae there too"

© Getty

ASTROPHYSICS

How hot does it get between galaxies in a cluster?

Many galaxies in the universe live alongside others, tethered to each other by their mutual gravity, to form giant clusters; the largest gravitationally bound structures in the universe. The galaxies in a cluster are only a tiny fraction of the total matter present – there's up to ten times as much mass in the form of a hot tenuous atmosphere filling the space between the galaxies, known as the intracluster medium.

The enormous gravitational field of the whole cluster – particularly that of the dominant but unobservable dark matter – squeezes this gas to heat it to extraordinarily high temperatures of millions of degrees. There is so much energy in this gas that the electrons are no longer bound to their atomic nucleus, but instead form a plasma composed completely of electrically charged particles. Too hot to be seen in optical images, this plasma is only observable in the X-ray waveband where it appears as a giant, smooth puddle centred on the most massive galaxy in the cluster.

The temperature of the intracluster medium is a puzzle – it radiates so much energy through its X-ray emission that it should have long since cooled down. The fact that it remains so hot requires a continual heating mechanism within the cluster, most likely related to the mechanical energy of sound waves travelling through the cluster gas. These waves in turn originate from disturbances caused by the active supermassive black hole found at the core of the central and most massive galaxy.

Dr Carolin Crawford, public astronomer at the Institute of Astronomy, University of Cambridge

Did you know?

Our galaxy is part of the Local Group of galaxies, residing in the Virgo Cluster.

Galactic clusters combine to create a massive superheated gravitational force

ASTROPHYSICS

How do we measure distances to space objects?

There are many methods to do this. Let me cite parallax, because we use it in our Gaia mission. For stars, we can exploit the fact that their position in the sky depends on our position as an observer. Much like nearer objects appear to move in front of background objects when you as an observer move, say, driving by a bunch of people in front of a landscape. In astrometry, we can use the fact move with the Earth around the Sun, so our observation position relative to the Sun changes by two astronomical units (AU) – about 300 million kilometres or 185 million miles – in six months. A star that moves by one second of arc due to the change in our position by 1 AU has a distance of one parsec (parallax second). One parsec is equal to 3.26156 light years, which is the distance light travels in 3.26156 years, and is equal to 30.9 billion kilometres (19.2 billion miles). With the Gaia spacecraft, for example, we can basically determine the distance of half of the Milky Way stars using this method.

For more distant objects, like other galaxies, we use 'standard candles'. Those are variable stars, the absolute brightness of which is correlated with the period of the variation. Knowing the variation, we can derive the absolute brightness. Knowing the absolute brightness and the apparent, measured brightness we can determine the distance. Even further objects, like quasars, are measured by looking at the redshift due to the cosmic expansion.

Dr Markus Landgraf, senior mission analyst at the European Space Agency (ESA)

> "For more distant objects, like other galaxies, we use 'standard candles'"
>
> **Markus Landgraf**

EXOPLANETS

Could humans evolve on other worlds?

The early history of the Solar System contained collisions and explosions. We know that the age of the Earth is around 4.5 billion years old. It's by coincidence that it is one-third the age of the universe. The Earth-Moon system was most probably made by a collision and by an object the size of Mars.

For hundreds of millions of years many meteorites, asteroids and comets bombarded the Earth. Life would not have formed in these early times because our planet was too hot and dry, so there would have been no possibility of this.

At around the same time that the rocks stopped falling, the Earth started to cool down. The first signs of an ocean started to appear. We even have fossils that show evidence of life within a few hundred billions of years – that's about the same time that life could have possibly occurred here. How life came to evolve on our planet is strong evidence that life can evolve elsewhere in the universe. Intelligent life – that's us – has only really turned up quite recently.

We ourselves are made out of star material. Stars that explode send chemical material into space. Some of it is recycled and some of it travels outside of our galaxy to make the next generation of stars that could have planets – worlds that could be like Earth. So that's the idea: stars explode and make future generations of stars and planets.

John Mather, an astrophysicist at NASA's Goddard Space Flight Center

We don't use literal candles to measure the distance to faraway galaxies...

The arrival of advanced life on Earth is relatively recent

© ESO; Getty;

SPACE EXPLORATION

Will we ever be able to travel backwards in time?

Einstein's theory of general relativity – our best theory of gravity, which has passed every experimental test so far – has some solutions that are sufficiently twisted to allow time travel to the past. These include wormholes and moving cosmic strings. Just as Magellan's crew went west around the world and arrived back in Europe, a time traveller can go steadily toward the future and yet circle back through curved space-time to visit an event in their own past.

If you built a time machine in the year 3000 by twisting space-time, you might be able to use it to go from 3002 to 3001, but you couldn't use it to go back to 2016 because that was before the time machine was built. It would take a supercivilisation to even attempt such a project. To know whether these time machines could be created in practice, we may need to learn the laws of quantum gravity, or how gravity behaves on microscopic scales. It's one of the reasons physicists find the possibilities of time travel so interesting.

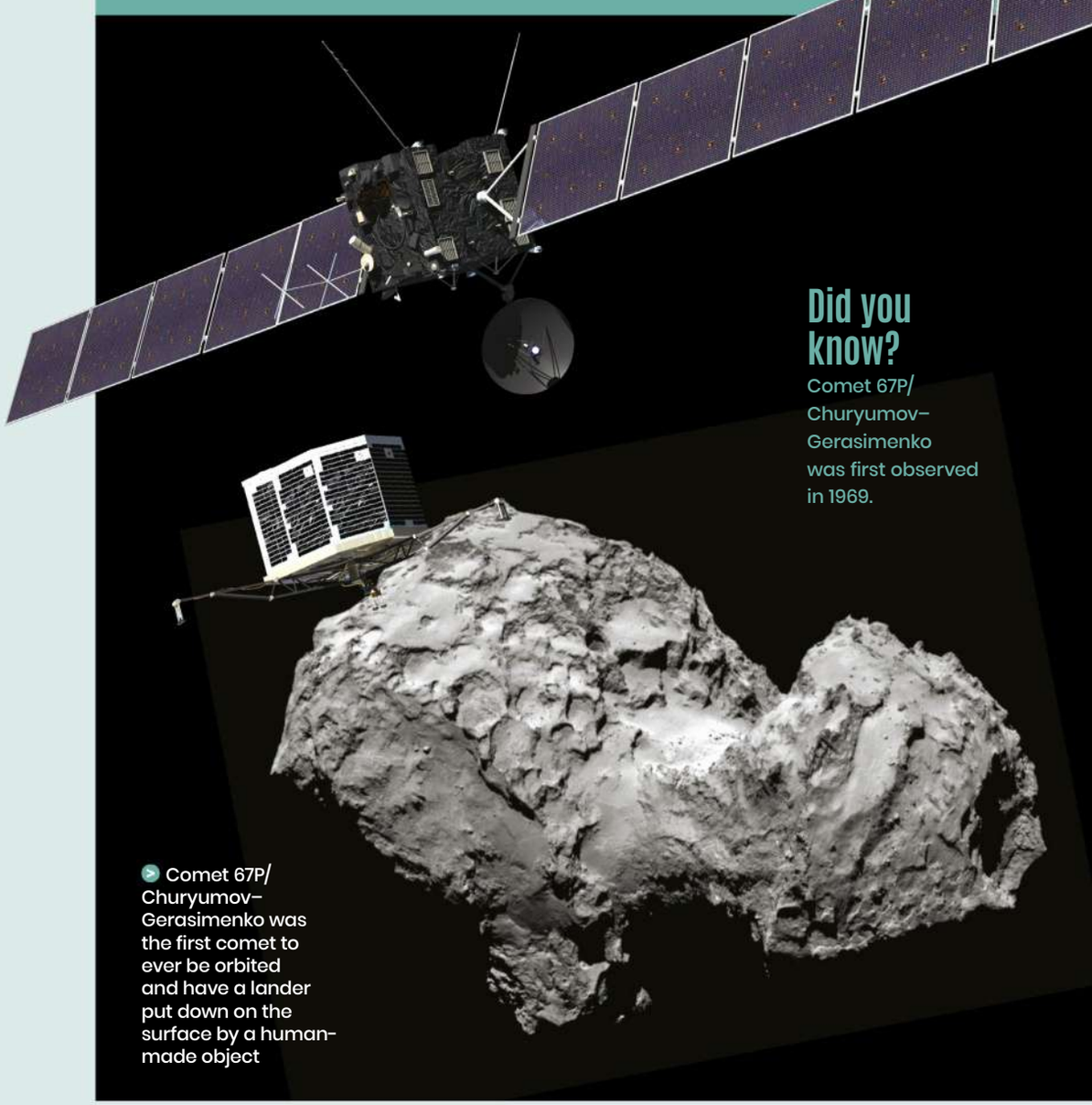
J. Richard Gott, professor at Princeton University

COMETS

What's so exciting about Rosetta's comet?

It is a fantastically diverse object. It had this very significant bilobed nature not uncommon in comets, but it really was striking with this duck shape. With regards to the surface features and the material we found, it kind of has all the bits of all the comets we've ever observed, and they were all in one comet that we were able to study. The reason we study them? Because we look at them as treasure chests of what the Solar System was like at its beginning. In fact, some of the stuff we were looking at with Rosetta, for instance the oxygen molecules we discovered on the comet, that was a surprise to us. Because it's there, it constrains how we believe the comet actually formed, so it actually says something about the protostellar cloud. It could be that there is material in that comet that predates the formation of the Sun. So just from studying this funny, duck-shaped object, to me it's mind-blowing that you can make that connection to the entire Solar System's formation. That's why.

Matt Taylor, project scientist of the ESA's Rosetta mission



Did you know?

Comet 67P/ Churyumov–Gerasimenko was first observed in 1969.

Comet 67P/ Churyumov–Gerasimenko was the first comet to ever be orbited and have a lander put down on the surface by a human-made object

© NASA; ESA; Getty

ASTROPHYSICS

Is our galaxy orbiting around an object in the universe?

Yes, the Milky Way does orbit something, and it also spins as it does so. Everything in the universe seems to be spinning while in orbit around something. The Moon spins as it goes around Earth; the Earth spins as it goes around the Sun; the Sun spins as it goes around the galactic centre 26,000 light years away.

In fact, the entire Milky Way spins as it moves in orbit around our neighbour, Andromeda, which in turn is also spinning. Around the Milky Way are two dwarf galaxies, the Large and Small Magellanic Clouds, and they will both eventually collide with us. A billion years later, the Andromeda galaxy will collide with us to form a giant future galaxy.

Interestingly, the orbital motions do not stop there, either. Our group of galaxies, called the Local Group, is falling towards the Virgo Cluster of galaxies some 40 million light years away. Us and Virgo are also moving towards the Great Attractor. In the universe, nothing ever stands still.

Our Milky Way galaxy orbits around the larger Andromeda

Things collapse under gravity, and like an ice skater on a rink pulling their arms in to spin faster, they may spin slowly to start with, but speed up as the collapsing objects become more compact.

Joss Bland-Hawthorn, Australian Research Council Laureate Fellow professor of physics and director of the Sydney Institute for Astronomy

SPACE EXPLORATION

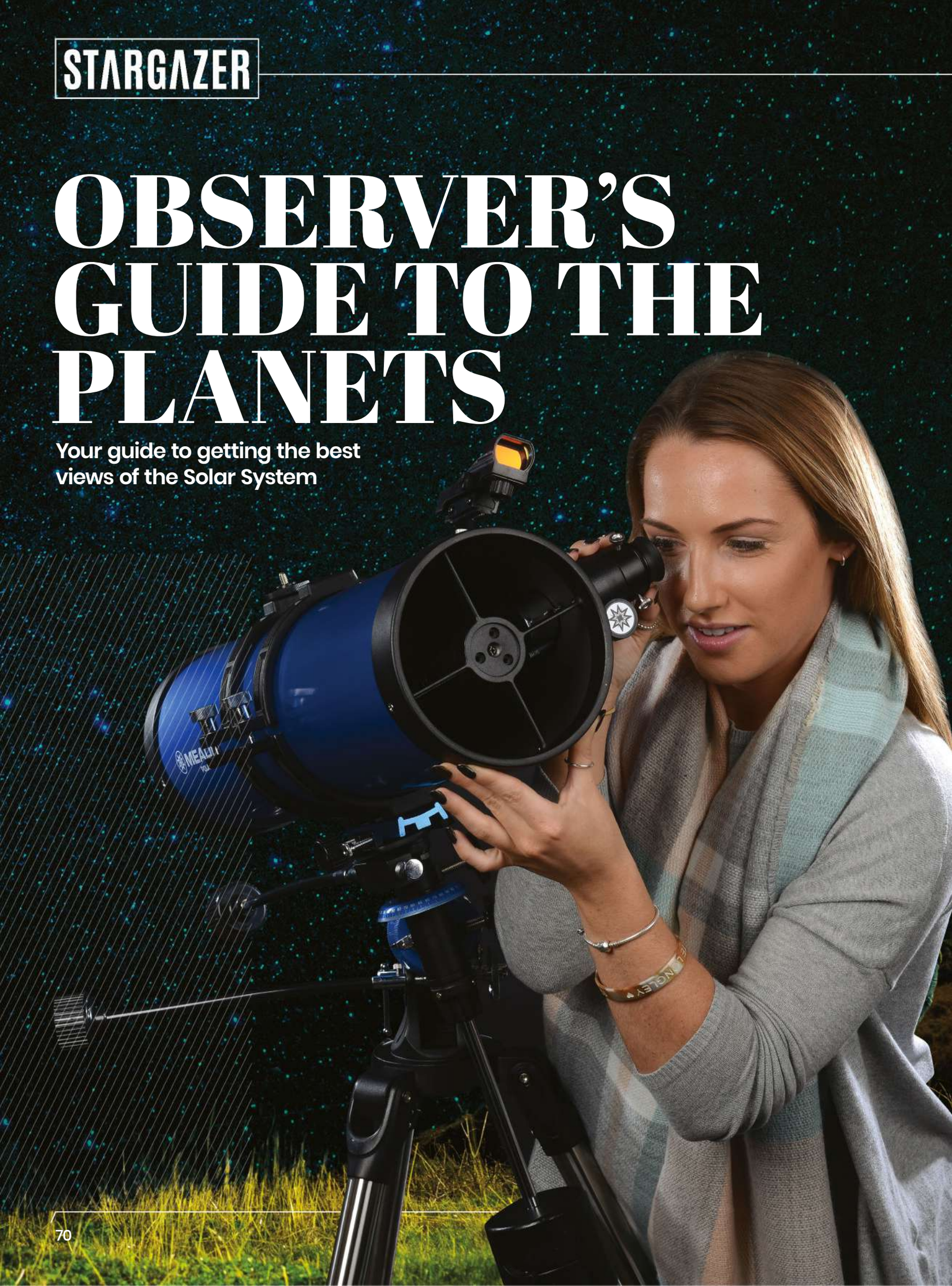
Is there a minimum height you need to be to become an astronaut?

There are indeed size restrictions on being an astronaut. NASA's limitations are listed as 62 inches (1.57 metres) for pilots and 58.5 inches (1.49 metres) for mission specialists. Limitations such as these often come from the size and layout of the spacecraft. People need to be tall enough to reach the controls and be properly secured within the craft. The Russian Soyuz capsule has an upper limit on astronaut size as well. Very tall people can't fit inside and thus cannot fly in them into space. Where possible these limitations are being lifted as more organisations are building human-rated capsules to take you into space. On top of this, the burgeoning industry of space tourism will want to be inclusive so will likely attempt to reduce these physical limitations of spaceflight.

Josh Barker, education team presenter at the National Space Centre

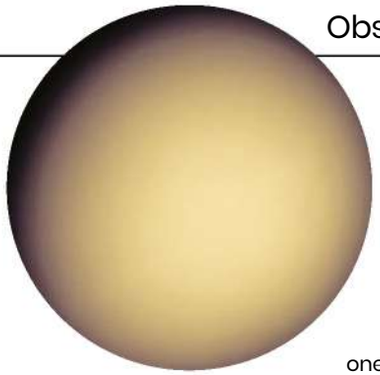
OBSERVER'S GUIDE TO THE PLANETS

Your guide to getting the best views of the Solar System



VENUS

Being between Earth and the Sun gives Venus – the brightest planet – its famous phases



Venus' phases are evident when observing it

Being the closest planet to us, it's no surprise that Venus is such an easy target to find in the sky. However, that doesn't tell the whole story. Due to its highly reflective atmosphere, Venus is considerably brighter than it should be, only outshone by the Sun and the Moon in the sky. The planet is enveloped in clouds of sweltering carbon dioxide laced with sulphuric acid that trap in a lot of the heat it receives from the Sun. With temperatures often tipping 460 degrees Celsius (860 degrees Fahrenheit), this runaway greenhouse effect makes Venus the hottest planet in the Solar System, even though it doesn't lie closest to the Sun.

Although not a star itself, Venus has long been known as the 'morning star' or 'evening star'. However, Venus' unique appearance differs in one striking way from a star – it doesn't twinkle. Stars twinkle thanks to Earth's atmosphere. They are so far away from us that we can only ever see them as tiny pinpricks of light. If a pocket of atmospheric dust and gas moves in front of that light, it can temporarily block it out entirely, meaning that from our perspective the stars seem to flicker on and off. Planets, however, are so much closer to us – being in the Solar System – that they actually appear as discs in the sky whose reflected light can never be blocked out entirely.

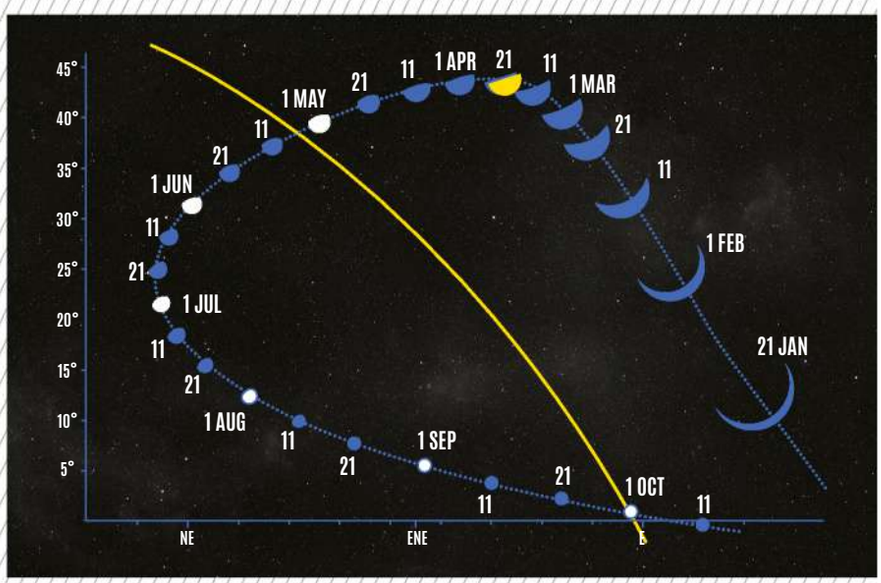
If you have a pair of binoculars, it's well worth pointing them towards Venus to see that disc up close. As always with binoculars, setting them up on a photographic tripod will give you a more stable view than the wobbling caused by holding them by hand. Looking at Venus, you should easily make out one of the most famous sights in astronomy: the phases of the second planet from the Sun. As it orbits closer to the Sun than we do, the amount of light Venus reflects towards us changes – in this sense it's similar to the phases of the Moon. When the planet lies far from the line between the Sun and Earth, we see phases akin to a first quarter and last quarter Moon, with the planet half illuminated. This point, known as greatest elongation, happens twice in Venus' 225-day orbit.

"Venus has long been known as the 'morning star' or 'evening star'"

By observing the phases of Venus you will be following in a long line of astronomical greats, most notably Galileo Galilei. The Italian astronomer was the first person to see the changing shapes of Venus in the early 17th century, immediately realising that it vindicated Copernicus' heliocentric idea that Earth orbited the Sun and not the other way around. Only if both Earth and Venus were circling the Sun, with Venus closer in than us, would we see this effect. That sounded the death knell for Ptolemy's geocentric idea that Earth was at the centre of the Solar System.

If you mimic Galileo's observations of Venus by using a telescope, there are some things to keep in mind. Firstly, and perhaps counterintuitively, it doesn't always pay to observe Venus when it's dark. The planet isn't far from the ground by the time the Sun is setting, even at greatest elongation. That means you are looking at the planet through deeper layers of haze and gas in the atmosphere, resulting in Venus significantly shimmering or wobbling in the eyepiece. Secondly, due to its extreme brightness, under magnification it can be dazzlingly bright. Both can be avoided by observing Venus during daylight hours – a particularly safe thing to do at greatest elongation as Venus is far from the Sun in the sky.

Your other angle of attack is to use telescopic filters. Yellow, blue or violet filters can help knock down some of the planet's brightness, and under great viewing conditions may even allow you to pick out faint surface features in the clouds. Alternatively, red and orange filters help dial down some of the sky's background brightness, especially good for observing Venus during the day against the blue light of the sky.



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MARS

The Red Planet's closeness to Earth offers the perfect opportunity to observe its features in great detail with the right equipment

When it comes to looking for the Solar System's planets in Earth's skies, Mars is perhaps the most distinctive. While we refer to it as the Red Planet, to the naked eye Mars appears to flit through pale orange-yellow to orange-red hues depending on its distance from Earth.

Summer on Mars brings about the onset of swirling dust storms that can sometimes grow so big they obscure the planet's surface completely. They tend to be most frequent around the solstice, and when blowing across Mars they appear bright orange and featureless. High-altitude clouds may also be on the increase during the Martian summertime, so this isn't the best time to observe the Red Planet.

When the planet isn't swathed in high volumes of Martian dust, the features that Mars has to offer are rewarding, but spotting them requires patience. You will also need eyes well-adapted to the dark – as well as skies devoid of light pollution – to pick out the fainter features, even with optical aid. We recommend at least a four to six-inch aperture with added magnification of 200x or more, where Mars will fill your field of view.

You can make picking out the Red Planet's less dominating dust storms, darker regions and volcanic stretches easier with the help of filters. Dark yellow or red filters will help you pick out any contrasting darker features, while a red or blue filter will reveal dust storms and Martian clouds respectively.

One other thing to be aware of when observing the Red Planet is the speed of its rotation, which is 40 minutes longer than the length of Earth's day. This means that at the same time each night on Earth, Mars will be a further 40 minutes out of sync, causing the face of the planet to look as though it's revolving backwards.

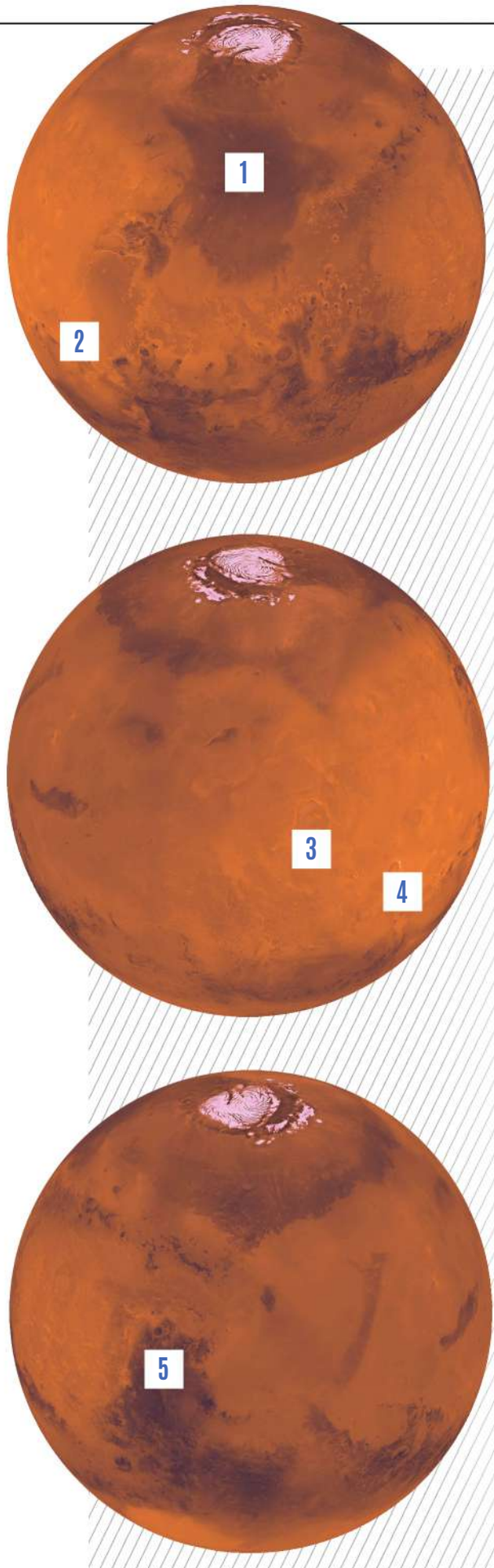
FILTERS AND MARTIAN FEATURES

Red
Use this filter for improving the definition of the darker and polar regions of Mars.

Deep yellow
This increases the contrast of Mars' polar caps, clouds and ice, as well as dust storms that rage across the Red Planet.

Medium blue
Use blue filters to enhance surface features, clouds, ice and storms on the surface.

Dark green
Increases the contrast of ice and polar caps on Mars.



THE FEATURES OF MARS

1 Mare Acidalium
The broadest and darkest feature visible on Mars, Mare Acidalium is a very prominent region that's easily picked up by a combination of telescope and eyes well-adapted to the dark.

2 Solis Lacus
Most commonly called the Eye of Mars, Solis Lacus is a dark feature on Mars that is frequently swamped by violent dust storms.

3 Olympus Mons
Olympus Mons is hailed as the largest volcano in the Solar System at around 22.5 kilometres (14 miles) high. If you have a blue filter handy – and are patient – you might be able to spot Martian clouds around the peak. You won't be able to see the caldera at the summit, though.

4 Tharsis Montes
A volcanic range very close to Olympus Mons consisting of three giant volcanoes: Arsia, Pavonis and Ascraeus Mons.

5 Syrtis Major
This appears as a dark V-shaped spot on the boundary between Mars' northern lowlands and southern highlands.

JUPITER

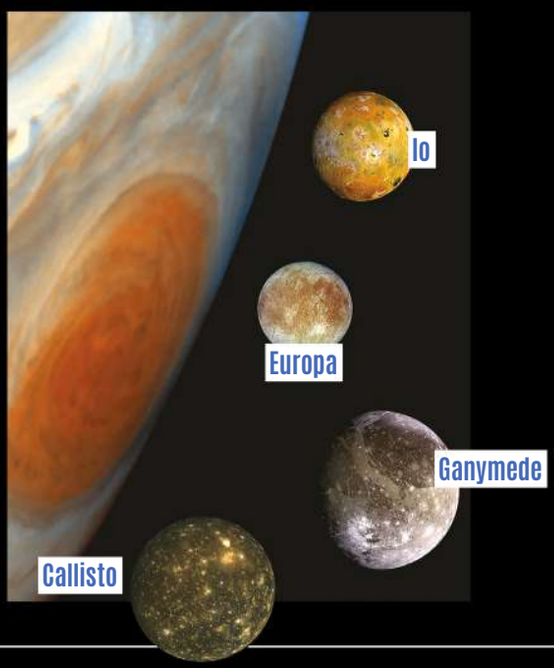
The king of the Solar System is a delight to observe with the naked eye or a high-power instrument

A dazzling Jupiter will be one of the first things you see when it's in the sky. At first glance you may mistake it for a plane. Watch for a few minutes, however, and it won't move. Nor will it twinkle like a star. Though it won't appear as bright as Venus, Jupiter is very easy to pick out with the naked eye, even with some light pollution.

The simplest equipment you can use to get a better view of the gas giant is a pair of binoculars. If you've not used binoculars before, they come in different sizes denoted by two numbers with an 'x' in between, for example 10x50. The first number is the magnification, the second the aperture of the lenses. Through binoculars, Jupiter will be revealed as a disc rather than a point-like star. You should be able to make out up to four bright lights on either side of the planet. These are the four biggest moons of Jupiter, collectively called the Galilean moons after Italian astronomer Galileo Galilei, who discovered them in the 17th century. One of the best things about these moons – Io, Europa, Ganymede and Callisto – is that they move around Jupiter at a rapid pace. Io, the innermost moon, takes just 1.8 days to complete an orbit, making the Jovian system a very dynamic thing to watch over a few nights. A good tip is to mount binoculars on a photographic tripod for stability – even small wobbles in your hands translate to big wobbles under magnification.

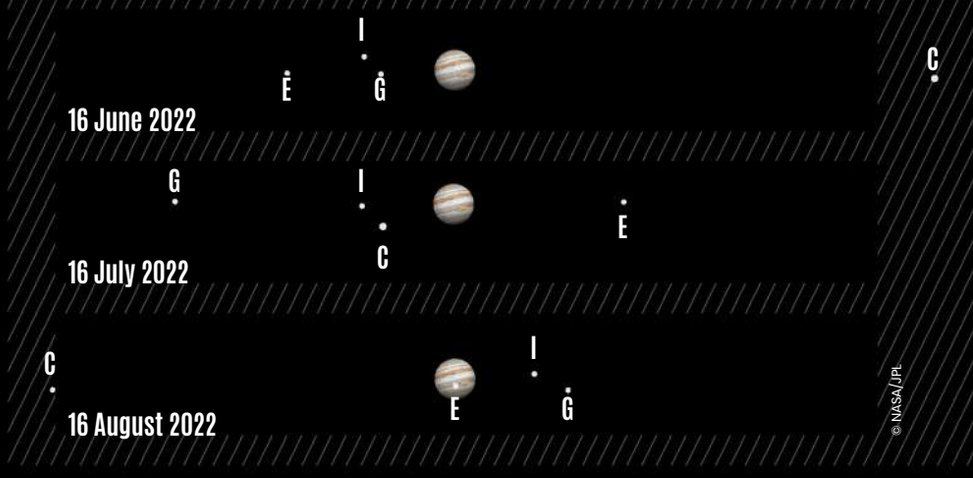
> "Though it won't appear as bright as Venus, Jupiter is very easy to pick out with the naked eye"

The next step would be to observe Jupiter with a telescope. Magnifications of 50x and upwards will begin to reveal the distinctive orange-banded structure of the planet's atmosphere. You may even be able to make out Jupiter's famous Great Red Spot in the southern hemisphere. It may be hidden from view, however. The planet's rapid, ten-hour rotation means the spot gets quickly carried to the other side. It should return after a couple of nights though, so keep checking back. The rapid rotation also leads to Jupiter bulging at the equator, and you should be able to discern this shape even through a modest telescope. More advanced observers might want to play around with coloured filters, which can alter the contrast of the cloud-banded planet, often leading to a sharper view.



THE DANCE OF JUPITER'S MOONS

KEY: G - Ganymede I - Io E - Europa C - Callisto



© NASA/JPL

SATURN

Take advantage of the ringed giant's spectacular viewing opportunities

Saturn is without a doubt one of the most beautiful planets in our Solar System. This is largely due to its famous and fascinating rings. There are a number of ways you can view Saturn. The naked eye shows it as a moderately bright star. Binoculars of almost any size will reveal Saturn's non-stellar nature – it becomes obvious that it's not just a star, but something with an appreciable disc, even if the binoculars are not powerful enough to show its ring system. They will also show Saturn's bright moon Titan. Titan orbits around Saturn in just over 15 days; you can follow this using binoculars or a small telescope. You can mark its position nightly by drawing a simple outline of Saturn and noting Titan's position each time you observe it. It's quite fun to do this and helps to show the orbit of this fascinating world around its host. Titan is roughly 50 per cent larger than our own Moon and has a thick atmosphere of methane, shrouding its surface from our view.

If you'd like to get a good view of Saturn, and especially the ring system, you need a telescope. A refractor with an aperture of three inches or a reflector with an aperture of around six inches is a good starting point to be able to give you a decent image of this distant world. Saturn does have cloud belts, much like Jupiter. However, these cloud belts are much more subtle and can be a little harder to spot. From time to time, storms have been spotted raging in the Saturnian atmosphere, often first detected by amateur astronomers.

But without a doubt it's the famous rings that draw the eye. Even a small telescope will show these, but there is a lot more detail available to larger

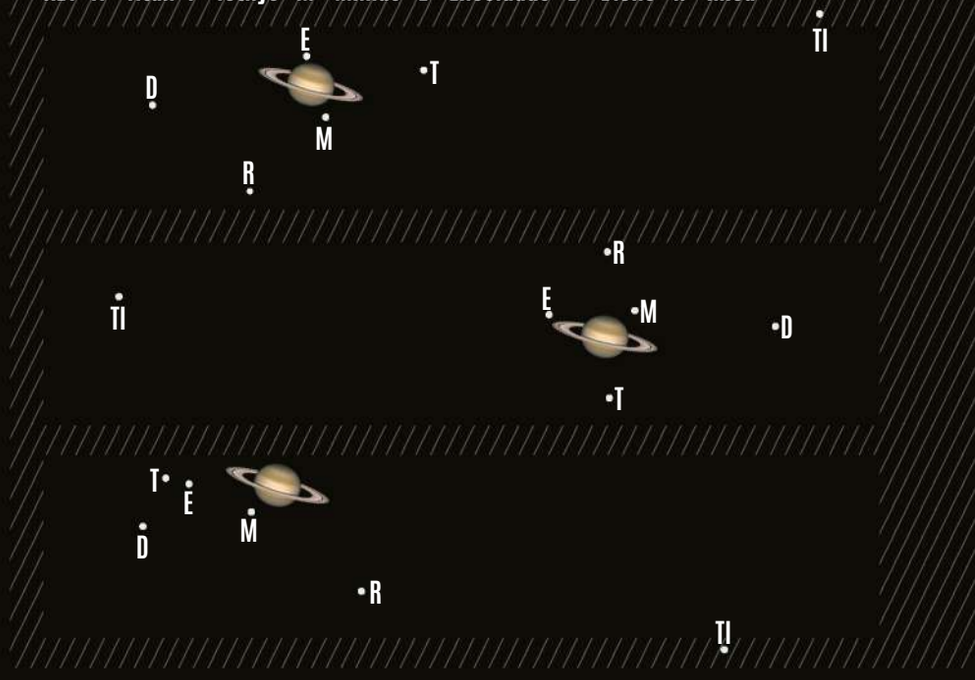
instruments. Saturn is one of the few bodies that benefits from significant magnification, in the region of 80 to 150x. One of the first things you'll notice on a clear night with even lower power is a dark gap in the rings. This is called the Cassini division, named after the Italian astronomer who first discovered it in 1675. The division is 4,800 kilometres (2,983 miles) wide and separates the rings into two bands: A and B. There are other distinct rings labelled C, D and so on, but these are difficult to make out with amateur equipment. There is one other division in the ring system that can be seen using amateur equipment, but it will need a larger telescope to resolve. This is called the Encke gap, which lies inside the A ring and is 325 kilometres (202 miles) wide.

Saturn's rings are usually tilted either towards us or away from us depending on how both Saturn and Earth are aligned in their respective orbits. The cycle of the axial tilt of the rings lasts approximately 30 years, moving from an angle of 27 degrees open, then through what's known as a ring plane crossing and onto the rings tilted once again at 27 degrees. But this time they tilt the opposite way, revealing the planet's southern hemisphere to us, so we see a ring plane crossing roughly every 15 years. At the point of the ring plane crossing, the rings seem to completely vanish. This is because the ring system is extremely thin, and as a result they are virtually impossible to see from Earth. At this time, Saturn's moons will be seen to line up with the planet's equator. Amateur telescopes should be able to show six of the moons quite clearly.

The shadow the planet casts on its ring system is easiest to see when the rings are tilted towards us; the shadow is not visible during opposition as the Sun is illuminating the planet directly. The rings also cast a shadow on the disc of the planet, but this can be quite hard to see in smaller telescopes.

FOLLOWING SATURN'S MOONS

KEY: TI - Titan T - Tethys M - Mimas E - Enceladus D - Dione R - Rhea

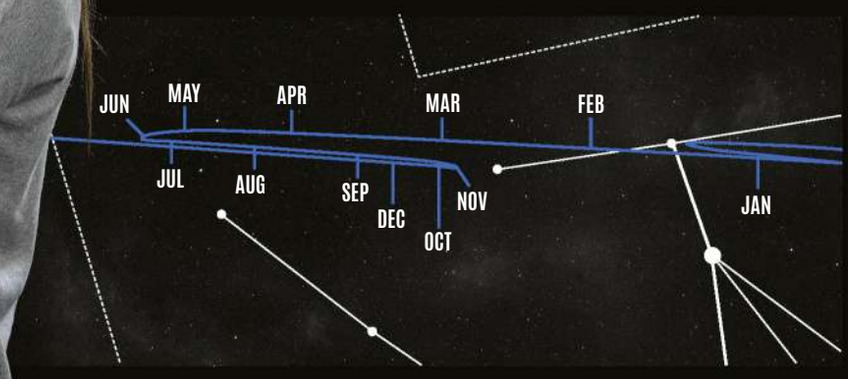


Coloured filters can be very helpful when observing Saturn. These are screwed into the eyepiece before insertion into the telescope's focuser. They help increase the contrast of the object you're observing and can also help reduce the effects of light pollution. They're usually inexpensive, and it's worthwhile having a selection of them to hand. You can experiment with different colours and see which features they help show. One of the most useful colours is blue, as this seems to increase the apparent brightness of the ring system as well as the cloud belts on the planet itself. A darker blue works well, especially for the rings, and violet can really bring up the detail. Orange is good for viewing the cloud belts and the polar regions, while a yellow-green filter can really show the Cassini division in the rings.

Once you've seen Saturn through your telescope, you're probably going to want to take a picture of it. You can sometimes get a reasonable snap of it using a smartphone camera held over the eyepiece, but holding this steady can prove difficult, and you'll need a driven telescope mount in order to keep the planet in the middle of the field of view as you try to photograph it. A better way is to use a DSLR camera fitted with an adaptor to marry it up to your telescope, rather than using the camera lens. You can also use a Barlow lens between the telescope and the camera to gain a greater magnification.

Alternatively, probably the best way to get a really good image of the planet is to use a webcam adapted for telescopic use or a dedicated astronomical video camera. Here the frames are combined or stacked in software designed to get the best possible contrast and detail and then processed to produce a fabulous image of the planet.

The Ringed Planet will draw you back to it time and time again, and whether you're viewing it with the naked eye or using binoculars or a telescope, there's always something new to see or image. If any planet has the wow factor, it's most definitely Saturn.



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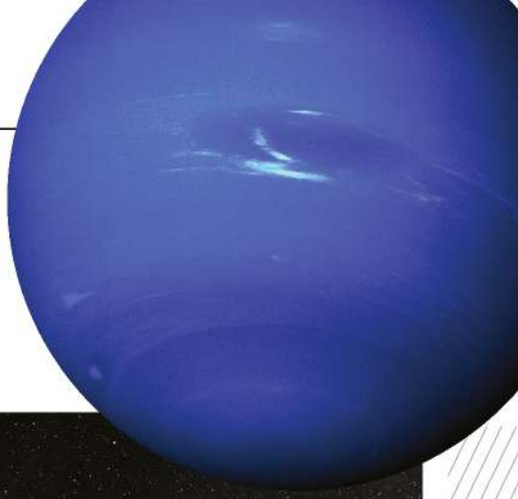
URANUS AND NEPTUNE

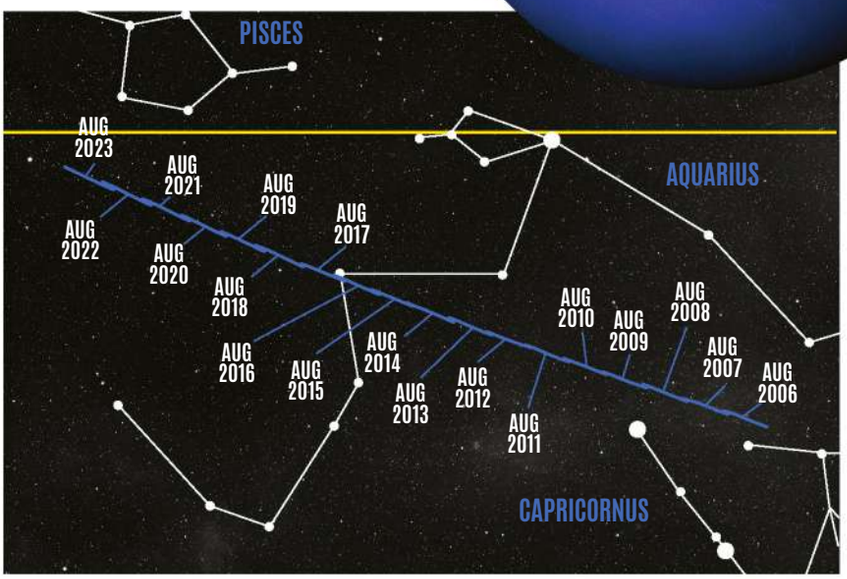
They're two of the most difficult planets to observe, so here's how to maximise your chances of viewing them



Uranus and Neptune are the hardest planets in the Solar System to see. This is because they are very far away. As the seventh and eighth farthest planets from the Sun, even at their closest points to Earth they are still 2.7 and 4.2 billion kilometres (1.7 and 2.6 billion miles) distant respectively. As a result they are fairly faint and are very small – just a few arcseconds across in the sky. But just because they are hard to see doesn't mean it's impossible... you just need to know where to look and with what instruments.

Uranus is the easiest of these two ice giants to spot. At magnitude +5.7 it is theoretically visible to the naked eye, but in practice – with all the light pollution and atmospheric haze around – very few people will see Uranus with just their eyes. Even in binoculars it will just look like a vaguely turquoise star-like point in the night sky. To see the disc of the planet Uranus, observers will need an eight-inch telescope at least, meaning it may be out of range of less well-equipped beginners.

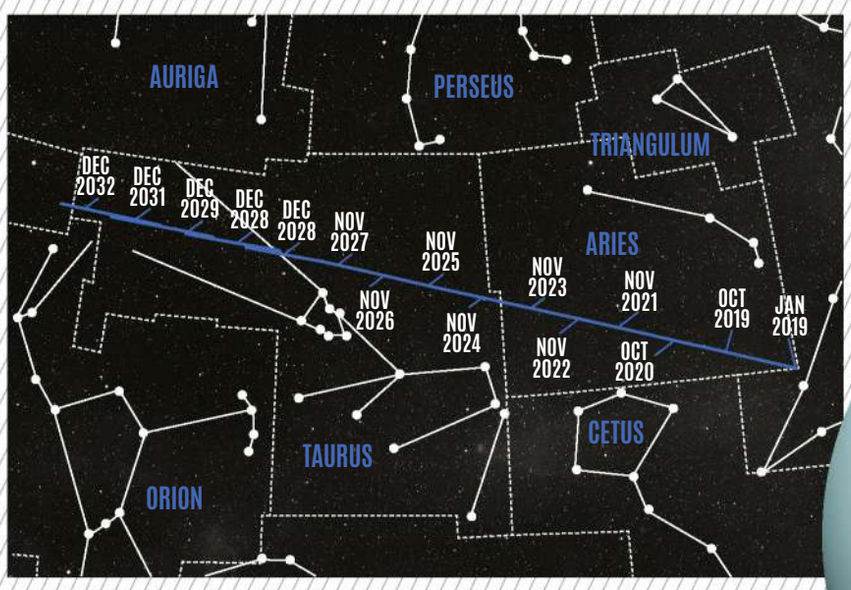
Uranus is a pretty dull planet to look at because there are no swirling bands of storm clouds like there are on Jupiter and its rings are so dark and faint that they will be invisible to amateur astronomers, unlike Saturn's beautiful rings. You may be able to identify some faint banding in Uranus' atmosphere, and filters will help you.



Uranus does have moons, but only a handful are visible from your back garden. The easiest are Titania – the biggest of its moons – and Oberon. It will be possible to spot these through a 12-inch telescope. Ariel and Umbriel are closer to Uranus, which makes them much more difficult to see and image, so you'll need an even larger telescope to do so, which not many people have. If you can see Uranus' turquoise disc through the telescope and at least two of its moons, congratulate yourself on a job well done.

Observing Neptune is more difficult. At magnitude +7.8 it can only just be seen in binoculars, but is more likely to be visible in a medium-sized telescope, although you probably will not be able to see it as anything more than a small, blue, round object just 2.4 arcseconds across. For comparison, remember that the full Moon is 1,800 arcseconds in diameter. Using a high magnification of 300x will help resolve Neptune's disc, but don't expect too much – if you can see it as anything other than a star-like point, you've done a good job.

The planet's largest moon is Triton, but at magnitude +14 you will need at least a 12-inch telescope, clear skies and lots of luck. It's often easier to capture Triton in images taken with your equipment instead.



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WHAT'S IN THE SKY?

What to look out for during this observing period

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16 JUNE
Mercury is at greatest elongation west in the dawn sky at -0.4

18 JUNE
Open cluster NGC 6530 is well placed for observation in Sagittarius

18 JUNE
The Moon and Saturn make a close approach, within 4°01' of each other in Capricornus

18 JUNE
Conjunction between the Moon and Saturn in Capricornus

21 JUNE
The Moon and Jupiter make a close approach, within 2°44' of each other in Pisces

22 JUNE
Mercury reaches half phase (dichotomy) in the dawn sky

22 JUNE
Conjunction between the Moon and Mars in Pisces

22 JUNE
The Moon and Mars make a close approach, within 50.6' of each other in Pisces

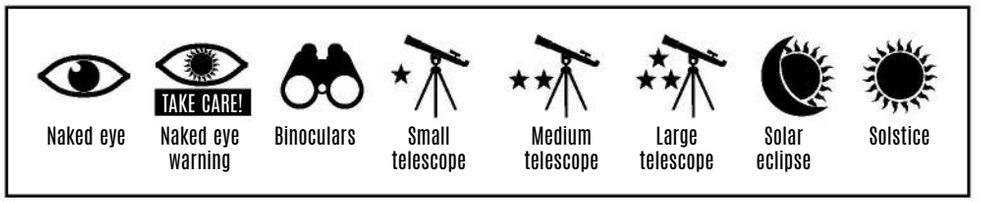
26 JUNE
Mercury reaches its highest altitude in morning sky

26 JUNE
The Moon and Venus make a close approach, within 2°35' of each other in Taurus

26 JUNE
Conjunction between the Moon and Venus in Taurus

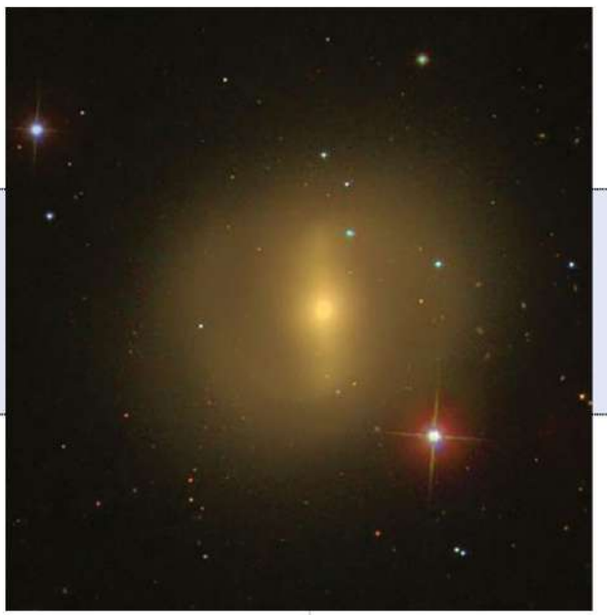
Red-light friendly
In order to preserve your night vision, you should read our observing guide under red light

02 JULY
Open cluster IC 4756 is well placed for observation in Serpens



18 JUNE

Open cluster NGC 4665 is well placed for observation in Virgo



21 JUNE

June Solstice

21 JUNE

Conjunction between the Moon and Jupiter in Pisces

22 JUNE

The Moon will pass in front of Mars, creating a lunar occultation

24 JUNE

The Moon and Uranus make a close approach, within 2.8' of each other in Aries

24 JUNE

The Moon will pass in front of Uranus, creating a lunar occultation

28 JUNE

Neptune enters retrograde motion

29 JUNE

Open cluster NGC 6633 is well placed for observation in Ophiuchus

01 JULY

Globular cluster Messier 22 is well placed for observation in Sagittarius

Jargon buster

Conjunction

An alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Declination (Dec)

How high an object will rise in the sky. Like Earth's latitude, Dec measures north and south in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and 60 arcminutes in a degree.

Opposition

When a celestial body is in line with Earth and the Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Right Ascension (RA)

RA is to the sky what longitude is to Earth, corresponding to east and west. It's measured in hours, minutes and seconds since as Earth rotates on its axis, we see different parts of the sky throughout the night.

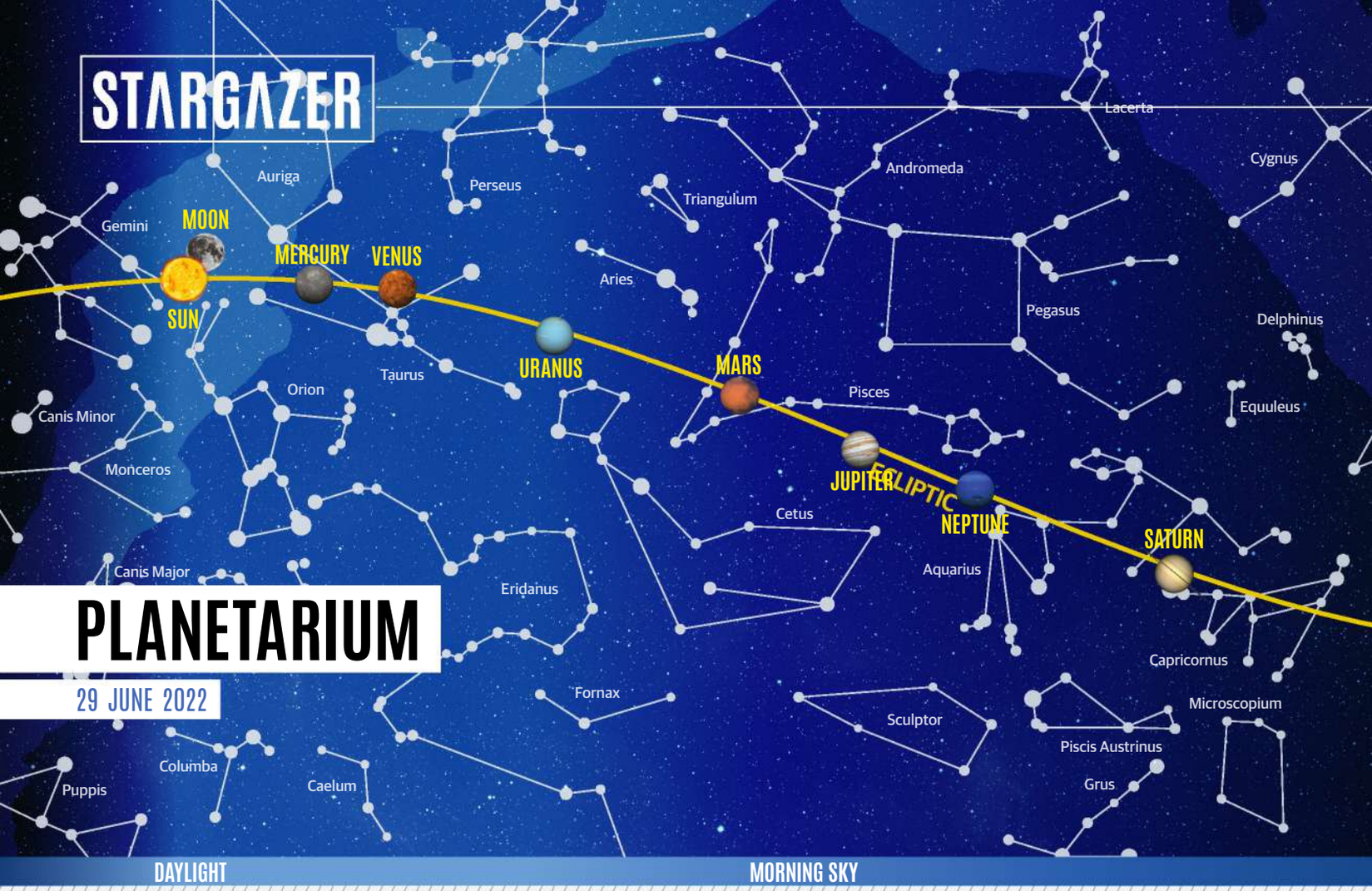
Magnitude

An object's magnitude tells you how bright it appears from Earth, represented on a numbered scale. The lower the number, the brighter the object. A magnitude of –1.0 is brighter than +2.0.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongation and as morning stars during western elongation.

© SDSS; Source: Wikipedia Commons/Credit: Ryan Bruels; Roberto Mura



PLANETARIUM

29 JUNE 2022

DAYLIGHT MORNING SKY

MOON CALENDAR

* The Moon does not pass the meridian on 12 July

15 JUN	16 JUN	17 JUN	18 JUN
99.5%	96.1%	89.7%	81.0%
05:03 23:10	06:14 23:59	07:40 --:--	00:32 09:09

19 JUN	20 JUN	21 JUN TQ	22 JUN	23 JUN	24 JUN	25 JUN
70.8%	59.9%	48.8%	38.1%	28.3%	19.5%	12.2%
00:55 10:36	01:13 11:58	01:27 13:16	01:40 14:31	01:53 15:45	02:07 16:58	02:23 18:11

26 JUN	27 JUN	28 JUN	29 JUN NM	30 JUN	1 JUL	2 JUL
6.5%	2.5%	0.4%	0.3%	2.0%	5.6%	11.0%
02:43 19:22	03:09 20:29	03:43 21:29	04:28 22:17	05:24 22:55	06:29 23:23	07:39 23:45

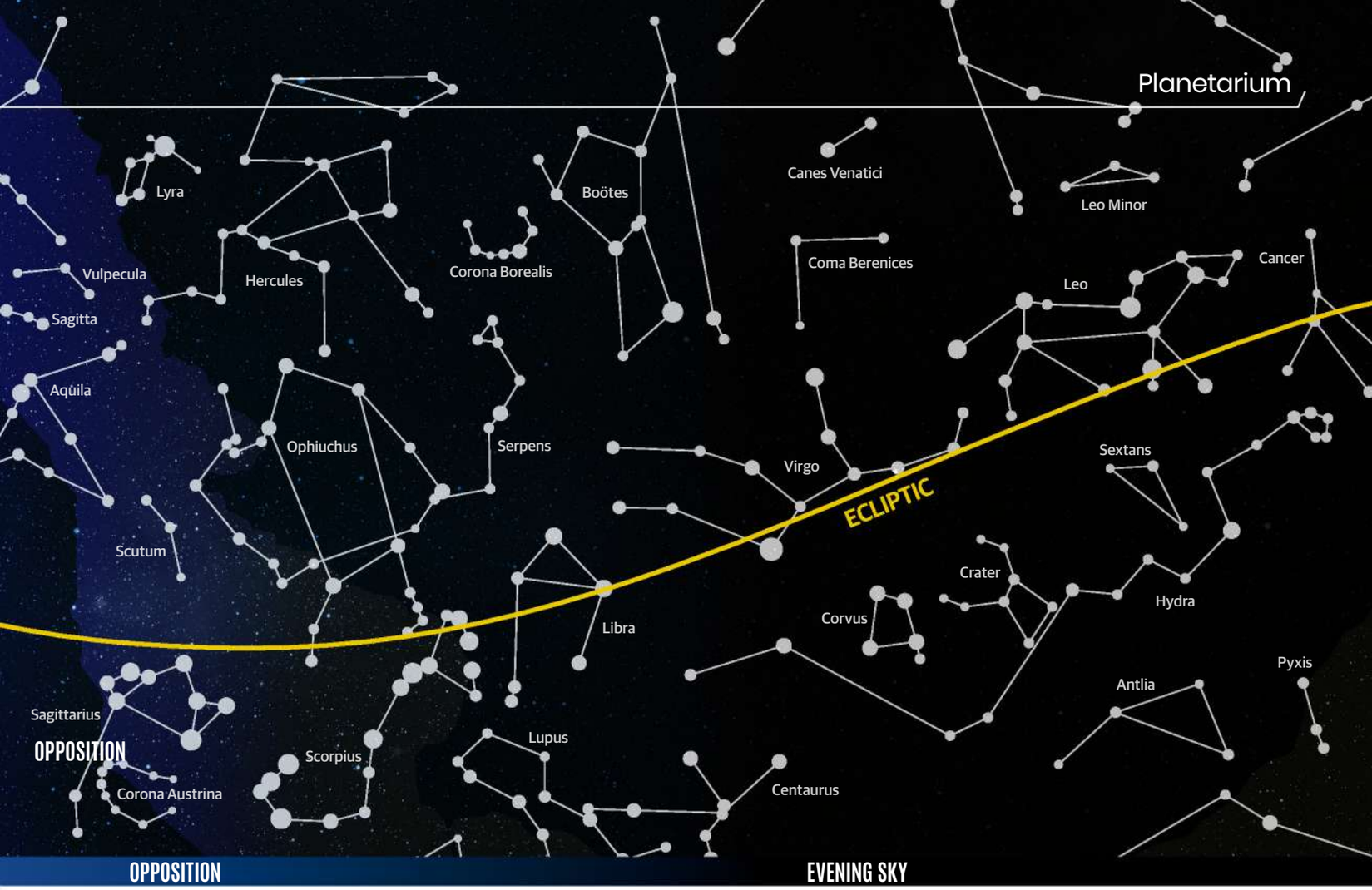
3 JUL	4 JUL	5 JUL	6 JUL	7 JUL FQ	8 JUL	9 JUL
18.0%	26.4%	35.9%	46.4%	57.4%	68.3%	78.7%
08:51 --:--	00:02 10:04	00:16 11:18	00:29 12:32	00:42 13:49	00:56 15:09	01:12 16:35

10 JUL	11 JUL	12 JUL	13 JUL FM
87.8%	94.8%	--:--%*	98.9%
01:33 18:04	02:02 19:31	02:45 20:48	03:47 21:47

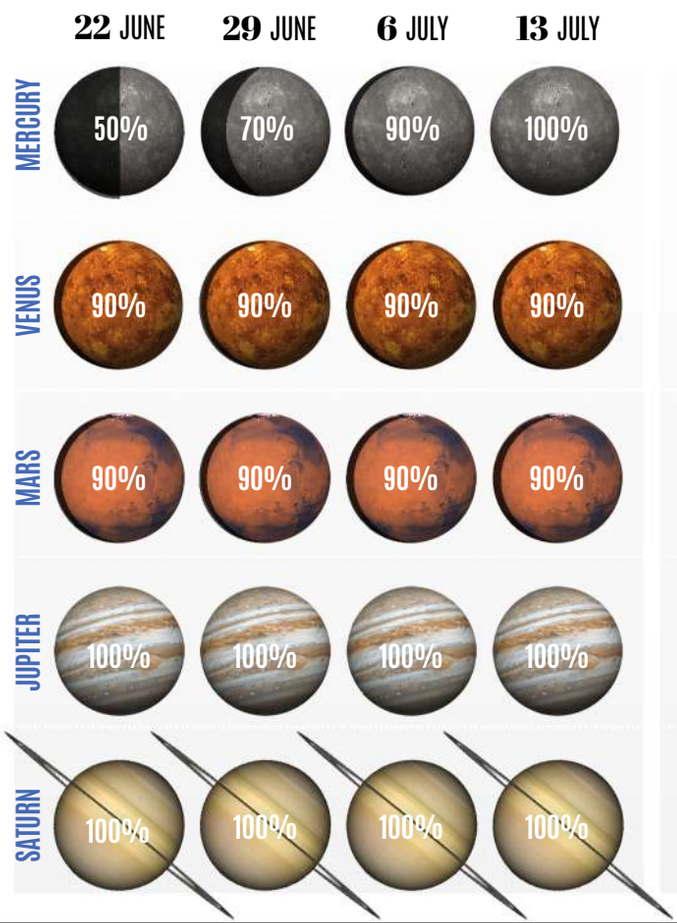
% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)



ILLUMINATION PERCENTAGE



PLANET POSITIONS

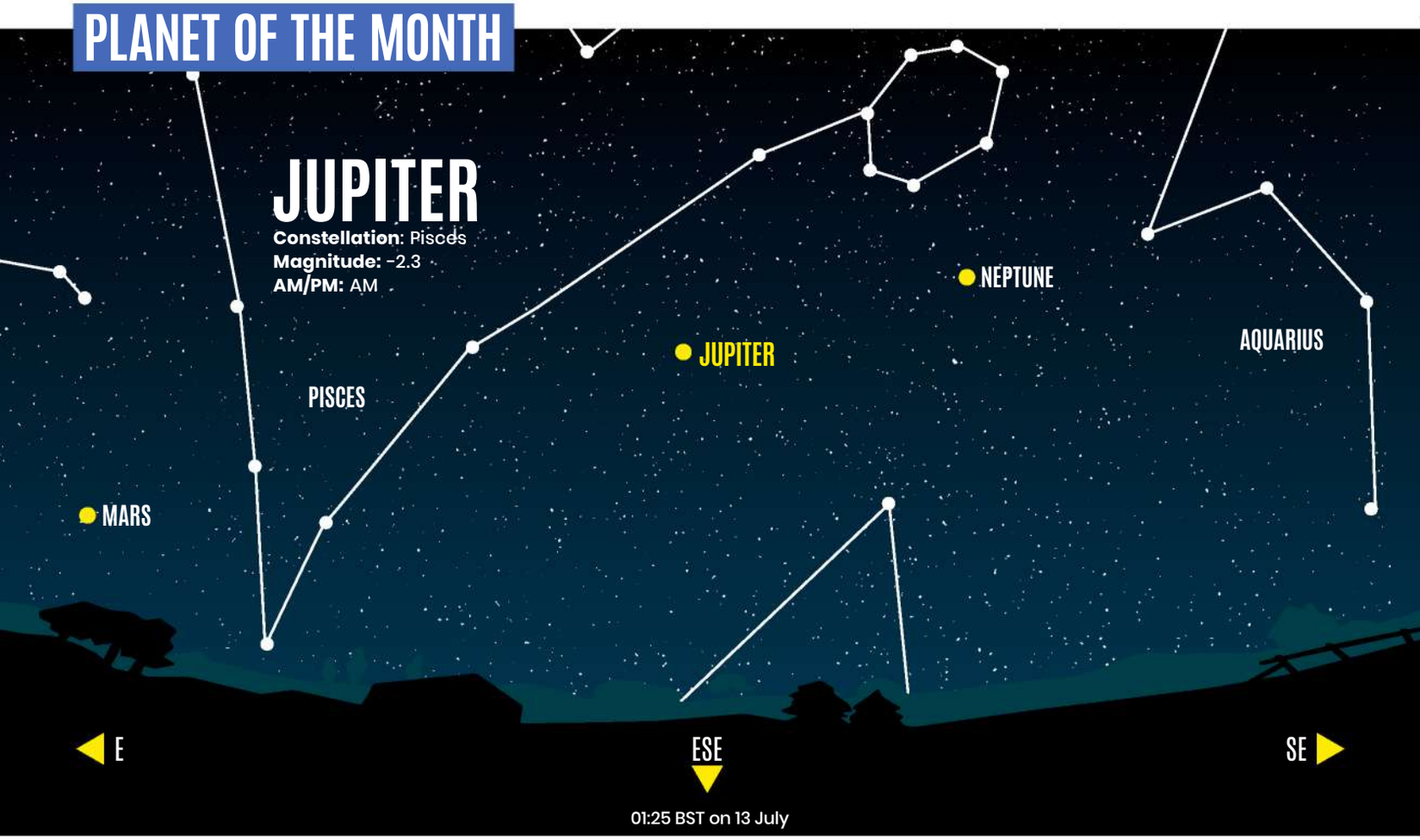
All rise and set times are given in BST

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
15 JUNE	03h 57m 38s	+16° 41' 38"	Taurus	+0.6	03:50	18:55
22 JUNE	04h 27m 19s	+18° 56' 34"	Taurus	-0.0	03:38	19:11
29 JUNE	05h 09m 51s	+21° 28' 55"	Taurus	-0.6	03:36	19:43
6 JULY	06h 04m 55s	+23° 23' 07"	Gemini	-1.2	03:50	20:23
13 JULY	07h 08m 50s	+23° 36' 44"	Gemini	-1.9	04:25	21:01
15 JUNE	03h 12m 55s	+16° 00' 55"	Aries	-3.9	03:09	18:07
22 JUNE	03h 46m 28s	+18° 11' 47"	Taurus	-3.9	03:02	18:26
29 JUNE	04h 20m 55s	+20° 01' 30"	Taurus	-3.9	02:57	18:44
6 JULY	04h 56m 14s	+21° 26' 25"	Taurus	-3.9	02:56	19:01
13 JULY	05h 32m 15s	+22° 23' 25"	Taurus	-3.9	02:57	19:16
15 JUNE	00h 58m 46s	+04° 19' 12"	Pisces	+0.6	01:59	14:50
22 JUNE	01h 17m 36s	+06° 14' 10"	Pisces	+0.5	01:40	14:51
29 JUNE	01h 36m 22s	+08° 05' 04"	Pisces	+0.5	01:22	14:52
6 JULY	01h 55m 01s	+09° 50' 59"	Pisces	+0.4	01:04	14:52
13 JULY	02h 13m 34s	+11° 31' 15"	Aries	+ 0.4	00:46	14:52
15 JUNE	00h 21m 55s	+01° 02' 21"	Pisces	-2.4	01:39	13:57
22 JUNE	00h 25m 02s	+01° 20' 34"	Pisces	-2.4	01:13	13:34
29 JUNE	00h 27m 42s	+01° 35' 41"	Pisces	-2.5	00:47	13:10
6 JULY	00h 29m 52s	+01° 47' 29"	Pisces	-2.5	00:20	12:46
13 JULY	00h 31m 30s	+01° 55' 49"	Pisces	-2.6	23:54	12:21
15 JUNE	21h 50m 10s	-14° 19' 28"	Capricornus	+0.7	00:27	10:06
22 JUNE	21h 49m 37s	-14° 23' 44"	Capricornus	+0.6	00:00	09:37
29 JUNE	21h 48m 45s	-14° 29' 28"	Capricornus	+0.6	23:32	09:08
6 JULY	21h 47m 37s	-14° 36' 32"	Capricornus	+0.5	23:04	08:39
13 JULY	21h 46m 15s	-14° 44' 46"	Capricornus	+0.5	22:36	08:09

THIS MONTH'S PLANETS

If you're a planetary observer, you're in for a treat from June through to July

PLANET OF THE MONTH



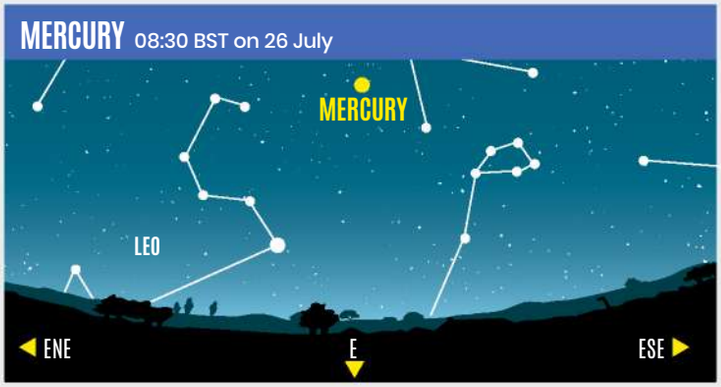
Venus will be brighter in the sky and Saturn will be visible for longer, but Jupiter will be the most visually striking of all the worlds stretched out across the predawn sky this month. All through the month ahead, Jupiter will be a bright 'morning star', and even the light of the predawn sky won't prevent it from being easily visible to the naked eye as a blue-white star, outshining the other worlds on either side of it.

In mid-June Jupiter will be rising two hours before the Sun, followed soon after into the sky by fainter, ruddier Mars. As the days pass and June slips into July, the two planets will appear to move apart, and as they do Jupiter will grow brighter and more obvious. By the end of our observing period in mid-July, Jupiter will be rising just after midnight, almost four hours before the Sun comes up, and will be a lovely sight low in the east.

To the naked eye Jupiter looks – and can only ever look – like a bright star, but if you have a pair of binoculars they will dramatically improve your view. They won't show you the planet's disc, as they're not powerful enough for that, but they will let you see the four brightest of its extended family of around 80 moons. These Galilean satellites – so called because Galileo first saw them with his primitive telescope in 1610 – can all be seen as tiny pinpricks around the planet. The number visible and their arrangement changes from night to night – when you look you might see all four on one side of Jupiter, a pair on either side or even just a couple of them. If you want to know in advance which ones you'll be able to see, there are lots of websites and free phone apps that will tell you.

If you have a small telescope, Jupiter really comes to life. You'll see its slightly squashed disc and creamy-yellow colour, crossed by horizontal bands of darker cloud. You might even catch a glimpse of its famous Great Red Spot – a storm several times the size of Earth which has been blowing for centuries. You'll also be able to see more of its moons too, and even the shadows of the Galilean satellites on Jupiter's cloud tops.

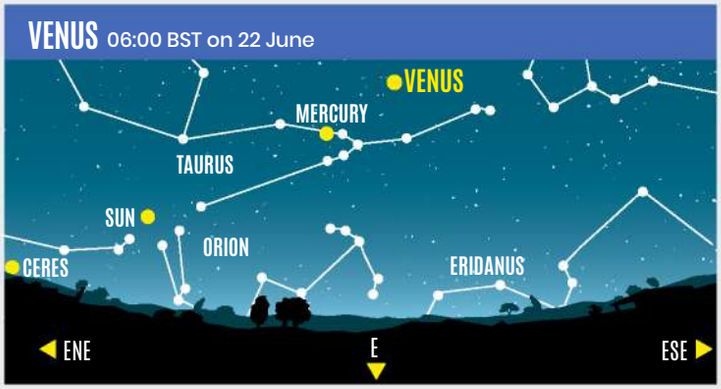
MERCURY 08:30 BST on 26 July



Constellation: Taurus **Magnitude:** +0.6 **AM/PM:** AM

At the start of our observing period Mercury will be very low in the northeast. Rising only half an hour before the Sun, it will be very hard to see in the bright morning sky. This small, heavily cratered world's visibility will improve briefly as the end of June approaches – rising an hour before the Sun, it will be visible in a darker sky.

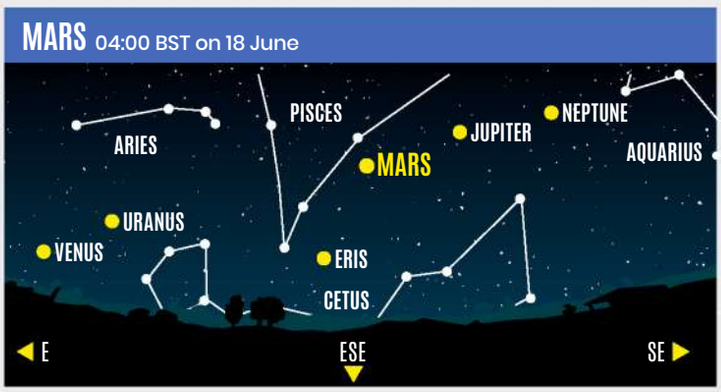
VENUS 06:00 BST on 22 June



Constellation: Aries **Magnitude:** -3.9 **AM/PM:** AM

This will be a great month to see Venus. Although the bright mornings and its proximity to the Sun will mean Venus won't look as dramatic or as spectacular as it does when it's shining in a dark sky, it will still easily outshine every other planet in view. In mid-June you'll find Venus shining to the upper right of much fainter Mercury.

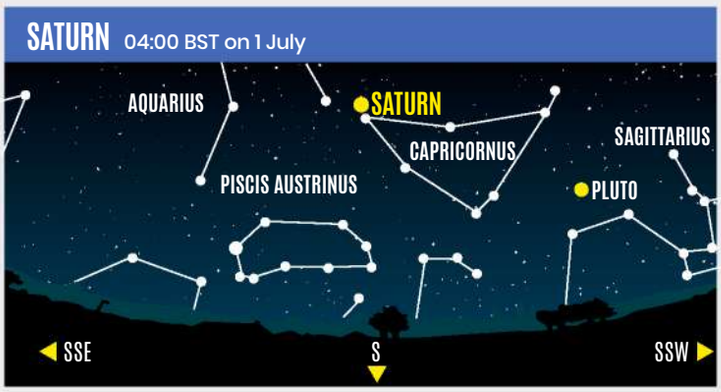
MARS 04:00 BST on 18 June



Constellation: Pisces **Magnitude:** +0.6 **AM/PM:** AM

Mars will be a morning object this month. Shining at magnitude +0.6, it will be easily visible to the naked eye as an orange-hued star, low in the east in the early hours. In mid-June it can be found to the left of much brighter and more obvious Jupiter and will be rising two hours before sunrise, following Jupiter into the sky.

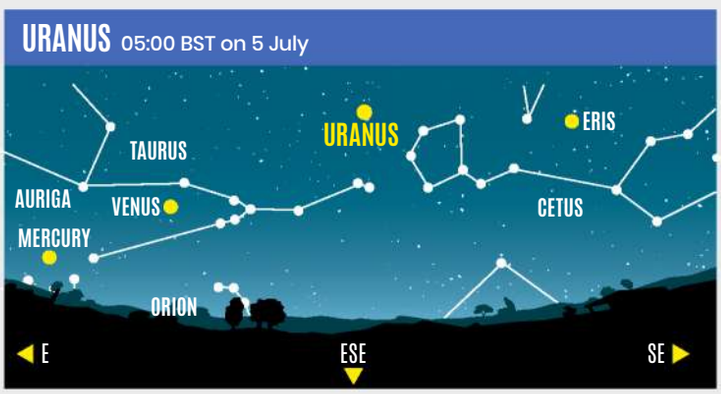
SATURN 04:00 BST on 1 July



Constellation: Capricornus **Magnitude:** +0.7 **AM/PM:** AM

Saturn will be easily visible to the naked eye, looking like a yellow-hued star low in the southeast in the hours before sunrise, and is probably the planet best placed for observation this month. In mid-June it will be rising three hours before the Sun, giving observers plenty of time to enjoy views of its beautiful rings in telescopes.

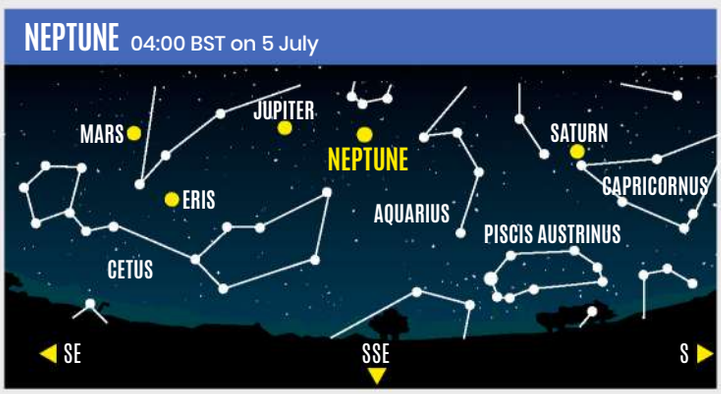
URANUS 05:00 BST on 5 July



Constellation: Aries **Magnitude:** +5.7 **AM/PM:** AM

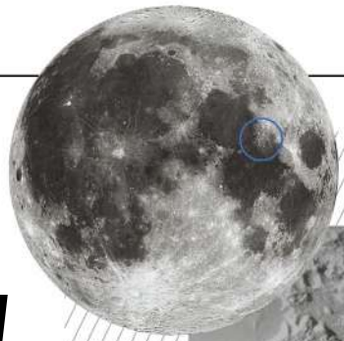
As June drifts into July, Uranus' visibility will improve dramatically. By mid-July it will be rising almost three hours before the Sun, making it visible in a dark sky for some time. The best time to see it will be between 02:00 and 3:00 on early to mid-July mornings, when binoculars will pick it out easily from the background stars.

NEPTUNE 04:00 BST on 5 July



Constellation: Pisces **Magnitude:** +7.9 **AM/PM:** AM

Even when the sky is dark and Moon-free, Neptune is so small and faint that a pair of binoculars or a small telescope are needed to see it. By mid-July its visibility will have improved, and the farthest Solar System planet from the our star will be rising four hours before the Sun, making it visible all through the early hours.



MOON TOUR

TAURUS-LITTROW VALLEY

Visit the historic landing site of the final Apollo mission

On 11 December 1972, the sixth and final Apollo landing took place when the Lunar Module Challenger set down on the surface of the Moon. It was a bittersweet occasion for thousands involved in the Apollo program and for millions of people around the world; after the incredible success of Apollo 11, which saw the world holding its breath and then erupting with joy as the first boots stepped onto the dusty surface, the Apollo program had been cut short, and missions scheduled to follow Apollo 17 had been cancelled.

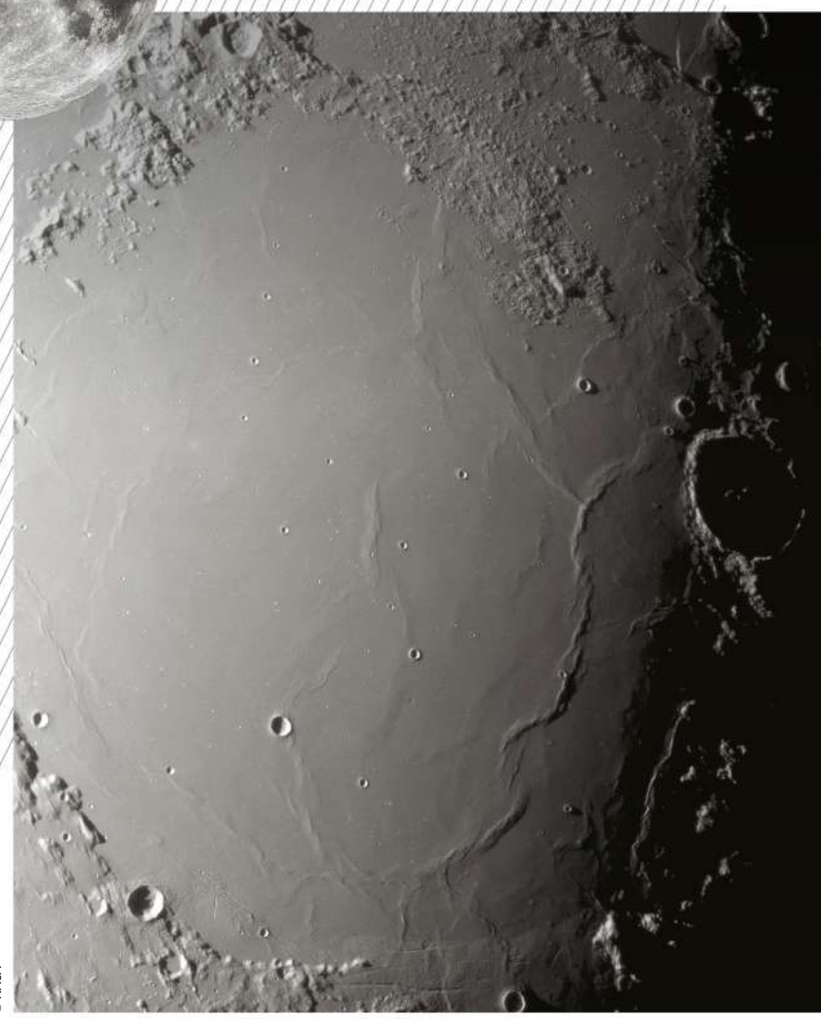
After reaching the Moon in triumph and exploring it with wonder and excitement, we were retreating back to Earth, called back early by politicians seeking to save money and responding to waning public support for and interest in the lunar landings. But before Gene Cernan famously became the last man on the Moon, hopped back up Challenger's ladder and closed the hatch behind him, he and geologist Harrison Schmitt spent three wonderful days on the Moon, having the time of their lives as they explored – both on foot and with the lunar rover – one of the most important and beautiful sites visited during the whole Apollo program, the Taurus-Littrow valley, which is our tour destination this month.

Finding the general area of the Apollo 17 landing site is actually quite easy as it lies on the border between two of the Moon's largest and most obvious features, namely Mare Serenitatis (the Sea of Serenity) and Mare Tranquillitatis (the Sea of Tranquillity), but you'll need a telescope to zoom in on the actual landing site itself.

If you look to the eastern 'shore' of the Sea of Serenity and follow the curve of the feature down past the well-known ringed crater Posidonius, then further down to where it meets up with the Sea of Tranquillity below it, where the two meet you will find the general area of Taurus-Littrow. Another route many lunar observers take to Taurus-Littrow is to follow the raptor-claw-like curve of Montes Haemus – the Haemus Mountains which form the western boundary between the two seas – to the crater Plinius and then hopscotch a little further east to the smaller crater Dawes. Another final small hop to the east takes you to a much smaller mountain range, Mons Argaeus, and nestled within the smiley-face curve of the range is a trio of hills. Directly between the two hills farthest from the mountains is the Taurus-Littrow Valley, where Challenger set down 50 years ago this December.

You'll need quite a large telescope and a high-magnification eyepiece if you're going to see the actual landing site itself. You won't be able to see any of the hardware used during the mission and left behind, the lunar rover's wheel tracks or the scuffed trails left by the moonwalkers' boots – they are only visible from orbit through the electronic eyes of satellites – but you will be able to see some of the major features the astronauts were surrounded by as they explored the stunning lunar landscape. As for the flag they planted, their dust-covered lunar rover and their Lunar Module's descent stage, surrounded by crazy-paving trails of bootprints and discarded backpacks, you'll just have to imagine those...

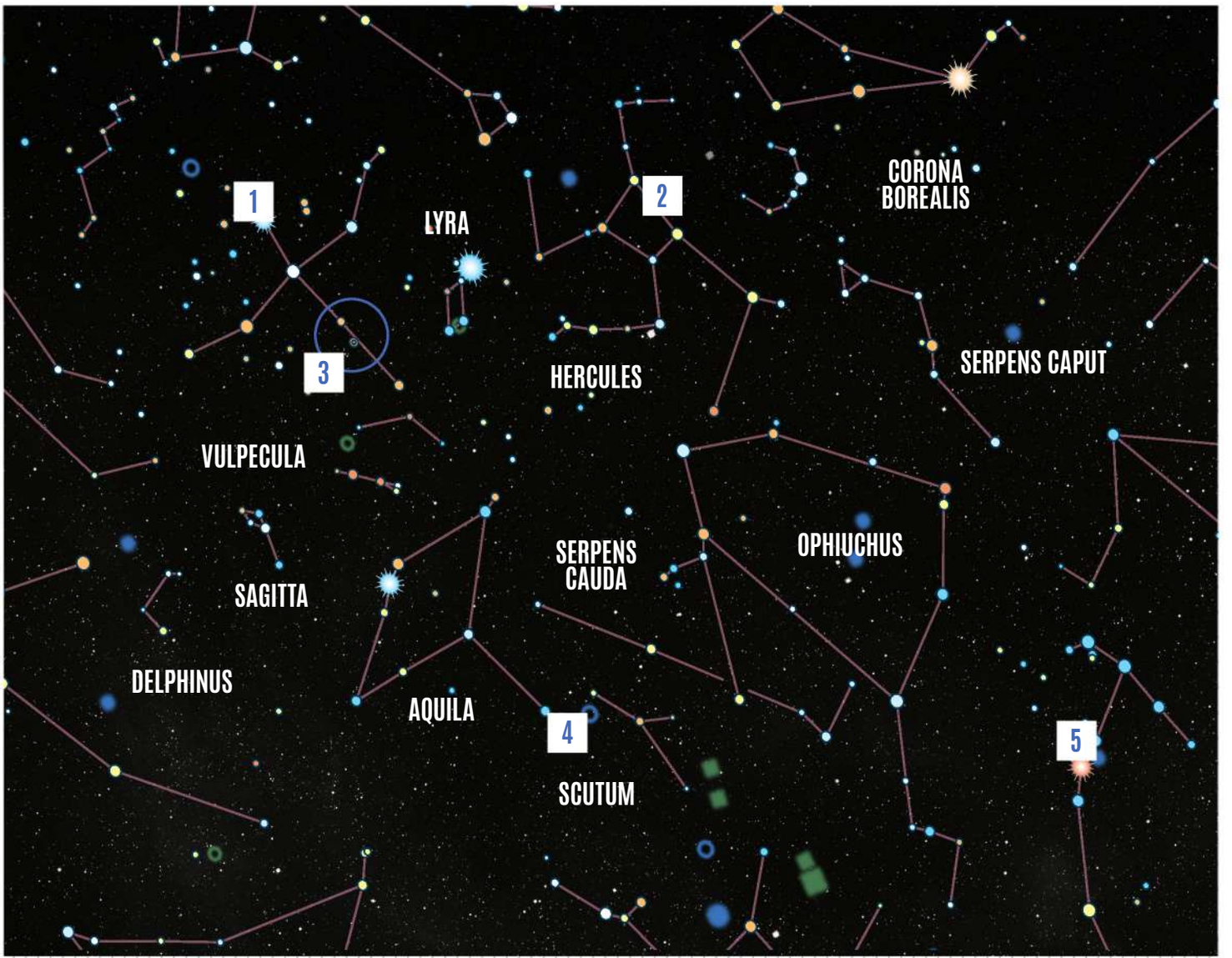
The landing site will be visible at the beginning of our observing period, when the terminator, the line between lunar night and day, will roll over it. For the next two or three evenings the Sun will be illuminating it from a low angle so its features will really stand out. The valley will be illuminated from a progressively steeper angle until by waning crescent it disappears. Not until 6 July will it begin to stand out again as the terminator rolls towards it. On 19 July the valley will be swallowed up by the gloom of lunar night once more.



© NASA

TOP TIP!

The valley will stand out most clearly when it is near the terminator, illuminated by the Sun at a low angle.



NAKED EYE AND BINOCULAR TARGETS

The summer Milky Way offers a plethora of targets

1 Deneb (Alpha Cygni)
At magnitude +1.25, Deneb is the 19th-brightest star in the sky. A blue-white supergiant more than 100 times wider than the Sun, it's between 55,000 and 200,000 times more luminous than our star. It will become the Pole Star around the year 9800.

2 Messier 13
Also known as the Great Globular Cluster in Hercules, Messier 13 is an enormous cluster of stars 145 light years wide and 22,200 light years away. This ancient star cluster, which looks like an out-of-focus star in binoculars, contains around 300,000 stars and was discovered by the great astronomer Edmond Halley in 1714.

3 Cygnus X
Look below Deneb and you'll see what looks like a long, misty 'cloud' to the naked eye. Through binoculars this is revealed to be a haze of countless millions of stars, looking like diamond dust spilled on black velvet. Sweep along it slowly with your binoculars for stunning views.

4 Scutum Star Cloud
Hanging low in the southern sky after midnight, the Scutum Star Cloud looks like a small, misty puff of cloud to the naked eye. Binoculars show it as a hazy smudge of stars with a brighter star cluster, Messier 11, embedded within it.

5 Messier 4
Look just to the right of the ruddy-red star Antares and you'll see a smudge of light out of the corner of your eye. This is the ancient globular star cluster Messier 4. It is 7,200 light years away and is more than 12 billion years old.

3 Part of the Veil Nebula, next to the Witch's Broom

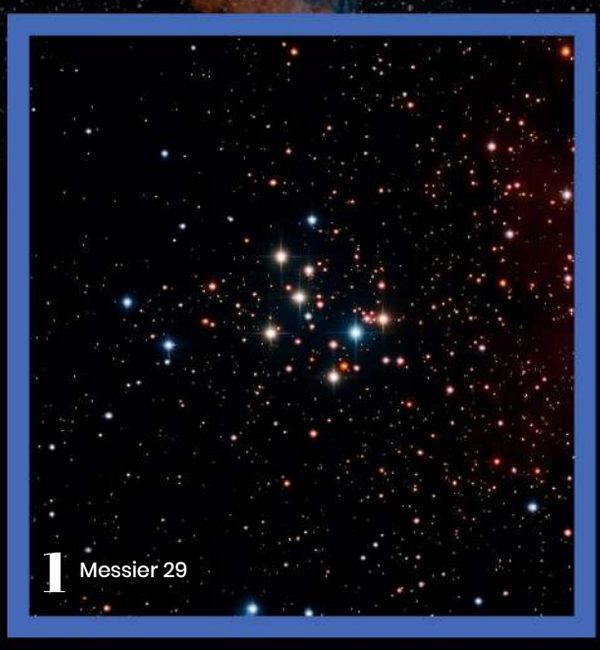
DEEP SKY CHALLENGE

SUMMER'S DAZZLING DEEP-SKY TREATS

On light summer nights, glittering star clusters, a dead star and a beautiful double star await

Usually we like to set you difficult observing challenges – faint star clusters or nebulae so misty they're almost not there – but as it's summer and the sky never gets dark enough to see the really faint fuzzies, this month's challenges aren't so tough. However, providing the northern sky isn't painted with a dramatic display of bright-blue and silver noctilucent clouds, if you stay up late the sky does get just dark enough to let you see some lovely sights through a telescope, and in the hours after midnight a telescope will give you very pleasing views of some beautiful objects.

Although the broad, frothy band of the Milky Way dominates the early summer sky, running right through Cygnus (the Swan) and cutting it and the whole sky in half, embedded in the Milky Way you will find the ghostly, rippled remains of dead stars and much more. Even a small telescope will give you a beautiful view of one of the loveliest and most popular double stars in the whole sky at the base of the Northern Cross. Don't believe those who insist that the summer sky is a write-off. As long as you don't mind a late night and bleary eyes the next morning, there's still lots to see.



1 Messier 29

1 Messier 29

This little-known magnitude +6.6 open cluster contains only a few scattered stars, forming the shape of an open box or chest. Small to medium telescopes pick it out nicely from the background sky.

2 Messier 39

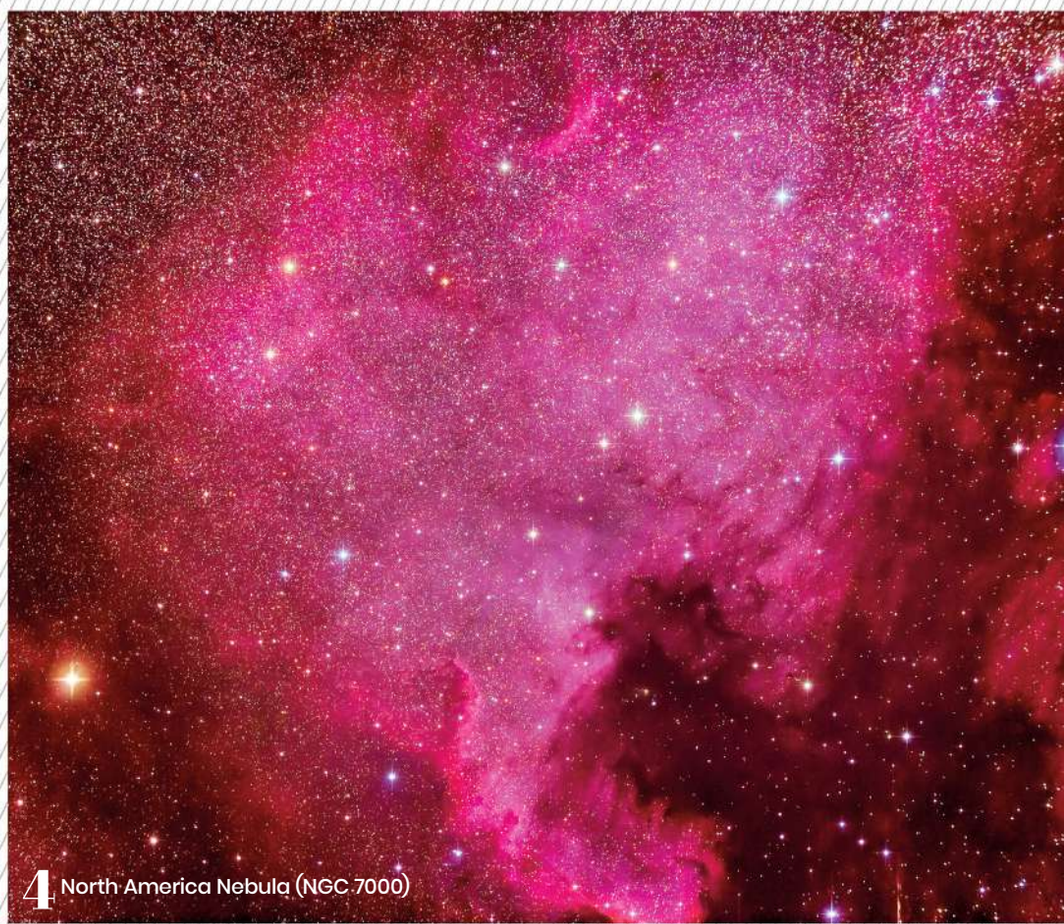
This loose open cluster, roughly triangular in shape, covers roughly the same angular diameter in the sky as the Moon. It is best seen through small telescopes using low magnifications.

3 Veil Nebula

The ghostly remains of a star that blew up between 5,000 and 8,000 years ago, the seventh-magnitude Veil Nebula consists of two arcs of faint gas. A medium-aperture telescope is definitely needed to show structure and hints of colour.

4 North America Nebula (NGC 7000)

Although this emission nebula covers as much sky as around four full Moons and can be seen in binoculars, a large telescope is needed to pick out its distinctive shape. Lower magnifications work best on light summer nights.

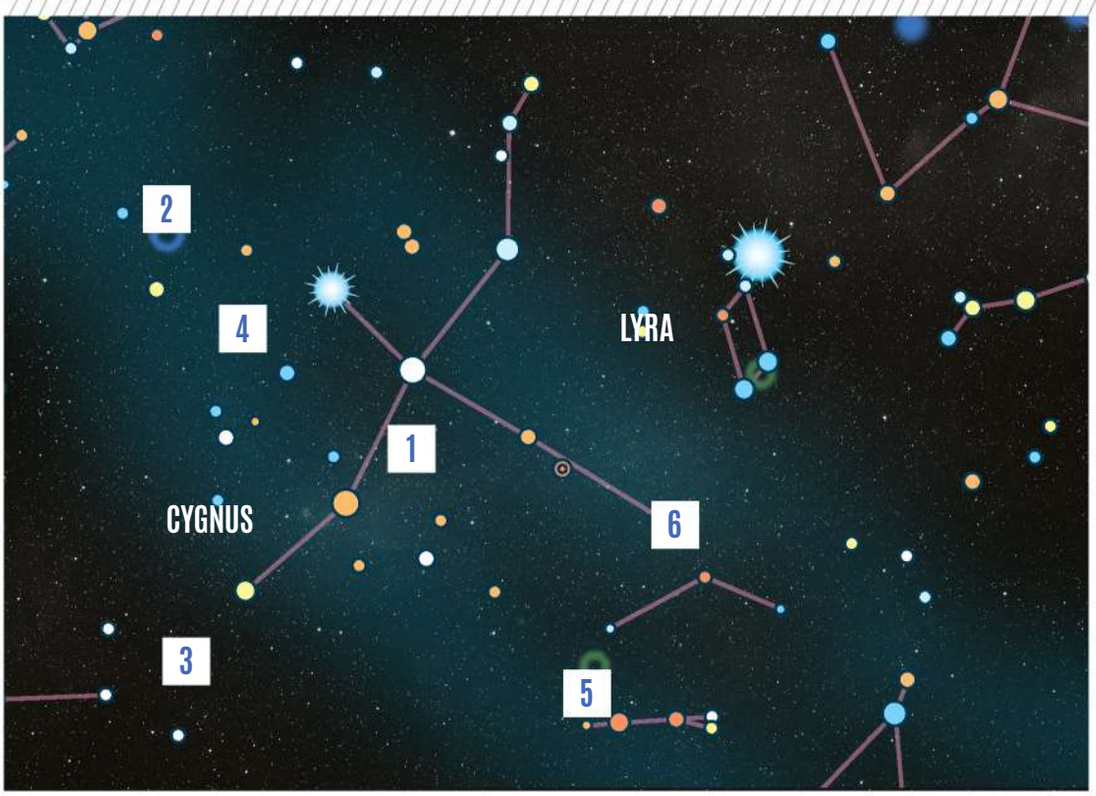


5 Dumbbell Nebula (Messier 27)

While the famous Dumbbell Nebula is just a small smudge in small telescopes, medium and large-aperture instruments will show its twin lobes of blue-green gas, and on still nights the +13.5 star at its centre too.

6 Albireo (Beta Cygni)

One of the most beautiful double stars, Albireo can be split into a third-magnitude gold star and a +4.7 sapphire-hued star, 50 centimetres (20 inches) apart, by even small telescopes. Larger scopes will also split the brighter star in the pair into two stars.



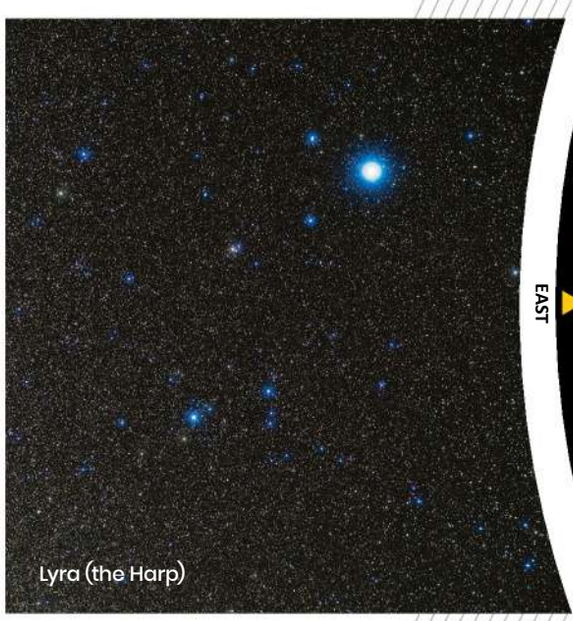
© Getty; Source: Wikipedia Commons © Veryoldphotons

THE NORTHERN HEMISPHERE

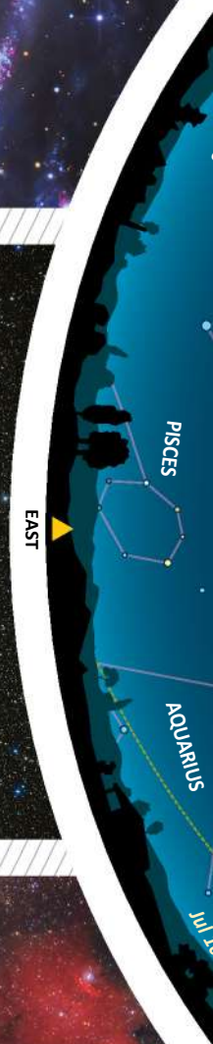
A selection of targets for whatever observing kit you have in your arsenal

Lyra, Aquila, Hercules, Sagittarius, Scorpius and Ophiuchus are within easy reach this month, packed with night-sky objects. Fans of tight-knit globular clusters should turn their attention to Ophiuchus and Hercules, where they will be rewarded with sights of the extremely stellar-rich Messier 10, Messier 12, Messier 13, Messier 14 and Messier 92. Astrophotographers will get great enjoyment from the binary star system Rho Ophiuchi in Ophiuchus, which is surrounded with a red emission nebula and very impressive light and dark-brown dust lanes. Cygnus is another great area to explore, with the Veil Nebula, Fireworks Galaxy and Crescent Nebula being excellent choices for observation.

Pinwheel Galaxy (Messier 101)


Lyra (the Harp)

Lagoon Nebula (Messier 8) and Trifid Nebula (Messier 20)



Using the sky chart

This chart is for use at 22:00 mid-month and is set for 52 degrees latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

Magnitudes

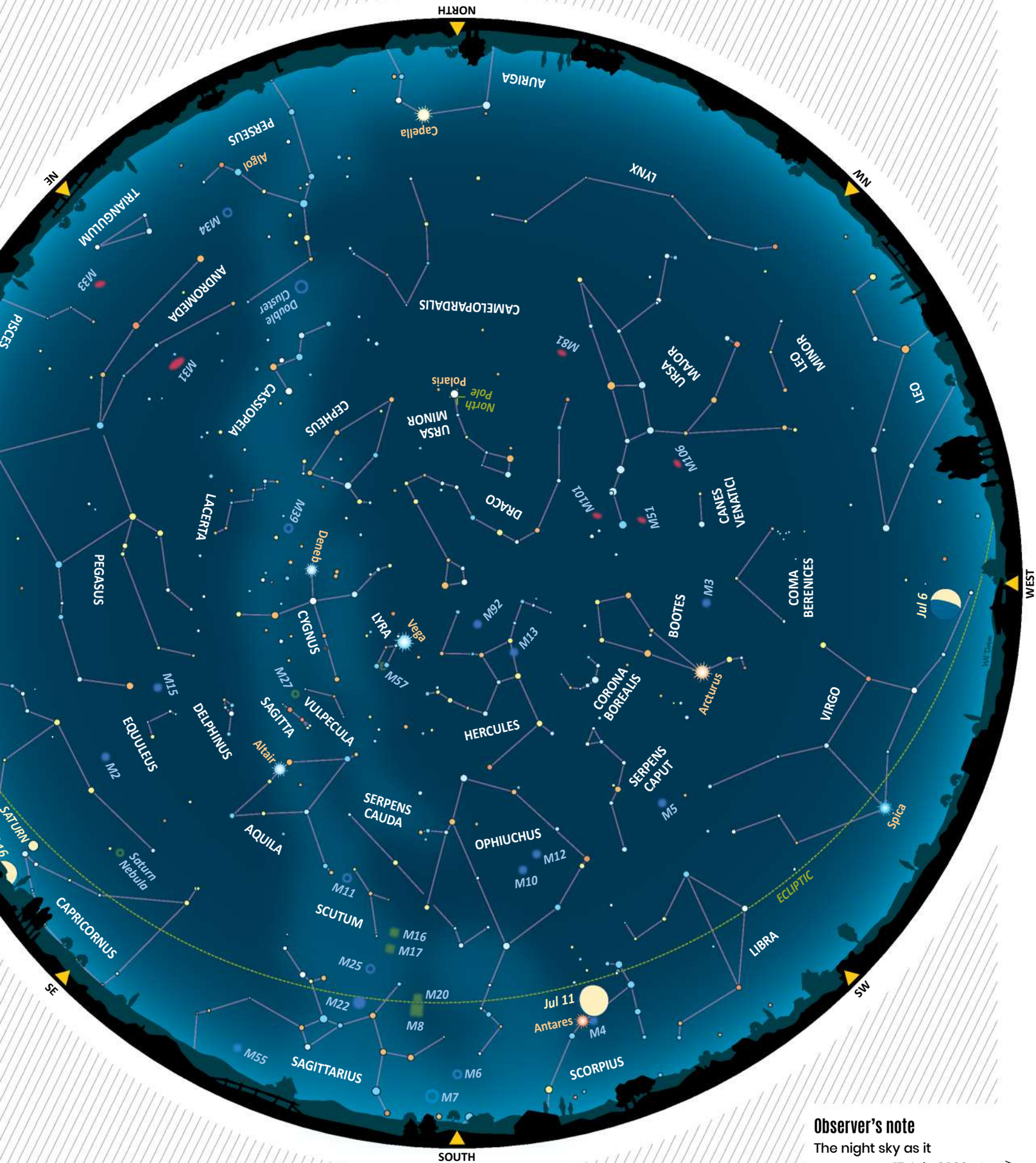
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to +0.5
- +0.5 to +1.0
- +1.0 to +1.5
- +1.5 to +2.0
- +2.0 to +2.5
- +2.5 to +3.0
- +3.0 to +3.5
- +3.5 to +4.0
- +4.0 to +4.5
- Fainter
- Variable star

Spectral types

- O–B
- A
- F
- G
- K
- M

Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



Observer's note
The night sky as it appears on 17 July 2022 at approximately 22:00 (BST)

© Getty

ASTROSHOTS OF THE MONTH

BASUDEB CHAKRABARTI

Location: Oria, Spain

Telescope: Takahashi FSQ-106ED and Telescope Live

"The clouds surrounding the star system Rho Ophiuchi compose one of the closest star-forming regions. Rho Ophiuchi itself is a binary star system visible in the light-coloured region on the right of the image. The star system, located only 400 light years away, is distinguished by its colourful surroundings, which include a red emission nebula and numerous light and dark-brown dust lanes. Near the upper right of the Rho Ophiuchi molecular cloud system is the yellow star Antares, while a distant but coincidently superposed globular cluster of stars, Messier 4, is visible between Antares and the red emission nebula."

Rho Ophiuchi

SOUMYADEEP MUKHERJEE AND MICHELE MAZZOLA

Location: Felizzano, Italy

Telescope: TS Optics 100Q

"This star cluster, the Pleiades, never fails to amaze. The 'Seven Sisters' are visible from all parts of the globe. For us, the people in the Northern Hemisphere, it is associated with the winter season. This image tries to capture the wonderful nebula along with the dust that can be seen around the region. Just above the star Electra, we were also able to resolve the very faint spiral galaxy UGC 2838, with a magnitude of +17.8. This image was acquired by Michele Mazzola and was processed by me."

The Pleiades

The Jewel Box star cluster

FERNANDO MENEZES

Location: São Paulo, Brazil

Telescope: Sky-Watcher Esprit 150 ED PRO

"The Jewel Box is an open star cluster 6,445 light years from Earth in Crux (the Southern Cross). It was called the Jewel Box by John Herschel, who described it as 'a coffin of gemstones of various colours. An exceptionally bright and beautiful object when viewed through an instrument of aperture sufficient to show distinctly the very different colour of its constituent stars, which give it the effect of a superb piece of jewellery.'"

REVIEW

LEGO NASA SPACE SHUTTLE DISCOVERY

A big kit with big fun, this set is an enjoyable build that's truly out of this world

Reviewed by Christina Hughes

MODEL ADVICE

From: LEGO

Price: £159.99 / $199.99

Model number: 10283

Pieces: 2,354

Finished item dimensions: 21 by 34 by 54 centimetres (9 by 14 by 22 inches)

Recommended age: 18+

NASA's Space Shuttle Discovery is an amazing feat of engineering, and we're thrilled to say that the LEGO Space Shuttle Discovery kit is too! You can tell that a lot of time and care went into designing this kit. The attention to detail will blow you away, from playing with the retractable landing gear to opening the payload bay and deploying the Hubble Space Telescope. From start to finish, the LEGO NASA Space Shuttle Discovery is a joy to build and will be an impressive display piece for any home.

Part of the advanced LEGO Creator Expert series, the LEGO NASA Space Shuttle Discovery is aimed at more experienced builders. It's recommended for those aged 18 or older – and we can see why, as it's got quite a lot of pieces – but this kit is perfectly suitable for patient older teens who are obsessed with all things space. The really cool thing about this LEGO Space Shuttle set is that it actually comes with two models – the Space Shuttle Discovery and the Hubble Space Telescope. Not only that, but it comes with multiple display stands so you can choose to show them off individually or together. If the LEGO NASA Space Shuttle Discovery set is a little out of your budget, consider the LEGO International Space Station for £59.99 ($69.99) instead – it comes with its own mini Space Shuttle Discovery!

With over 2,000 pieces, this is a big build that you can really sink your teeth into. Pieces were separated into bags labelled 1 to 17, with 18 bags in total as there were two #2 bags. It took us about a week of evenings to complete across around eight hours in total, but if you fancied powering through the LEGO NASA Space Shuttle Discovery kit, it could be completed over an intense weekend. However, we advise that you treat this build as a marathon rather than a sprint. If you go too quickly, or build for too long, you'll get tired and make mistakes – and as most of the pieces are white, you'll want to keep your wits about you.

You start off by building Hubble and then move onto the main event. As it's a mostly symmetrical build, some people might find this a bit boring, but we found that they spaced out the repeated sections in a way that didn't feel too repetitive – in fact, it felt more mindful than annoying. It was also really interesting putting together the clever mechanisms that make certain parts of the Space Shuttle Discovery move, such as the elevons on the wings.

One of the trickiest parts of the build was getting all the shiny mirrored stickers onto the large, curved white panels. Lining them up can be a bit fiddly, but we found that placing one edge of the sticker on the end

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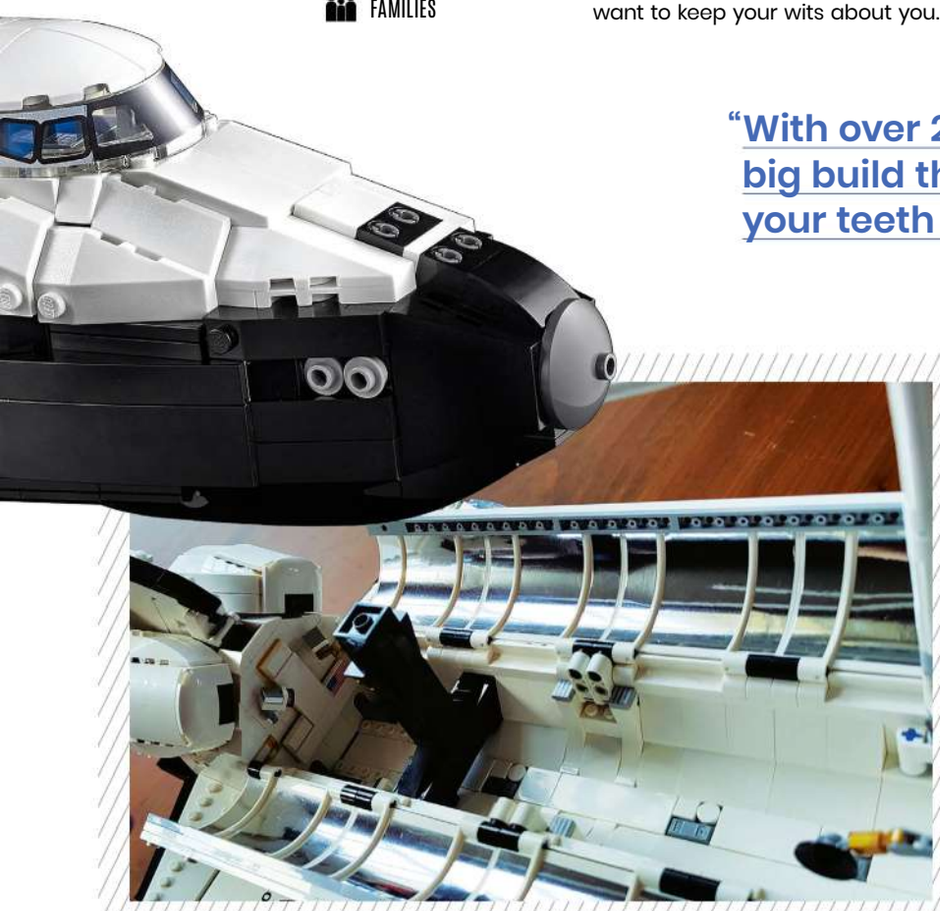
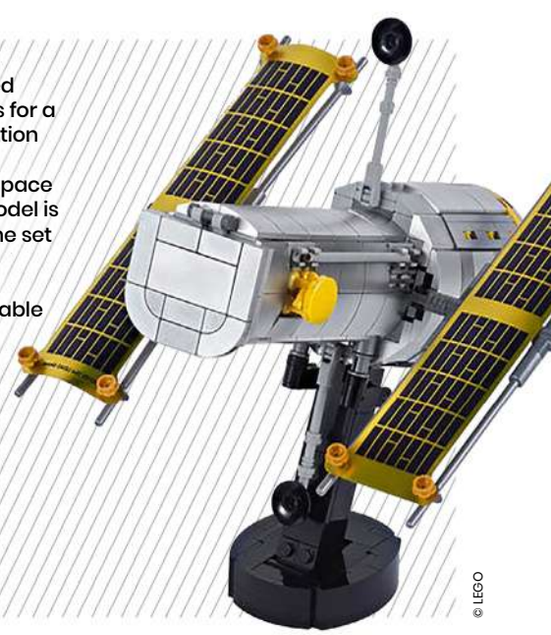
"With over 2,000 pieces, this is a big build that you can really sink your teeth into"





The finished model makes for a great decoration

A Hubble Space Telescope model is included in the set

The model features a usable payload bay

© LEGO

of the little orange tool – the brick separator that comes with all large LEGO sets – and then lining this up against the edge of the panel made sticker placement much easier. This way, if you start laying the sticker down and notice it's at a bit of an angle, you can pull it back up again using the orange tool without damaging the sticker.

Once assembled, the LEGO NASA Space Shuttle Discovery isn't just for show - there are several movable parts to play with. You can pop the landing gear out, deploy the robotic arm and even the split rudder is functional. One of our favourite details is that the cockpit opens up and you can see all the controls inside.

The only real negative thing we have to say about this kit is that there are no LEGO Minifigures included. Due to the size of the LEGO NASA Space Shuttle Discovery, we understand that any included Minifigures wouldn't have been to scale, but it would have been nice to have a token astronaut anyway – maybe they could have stood next to the information placards that come with each model.

Overall, the attention to detail is just amazing. For example, did you know that on the starboard side of the Space Shuttle Discovery the American flag is actually backwards? This is because regulations require that the American flag must always fly with the stars forward so that the flag looks like it's trailing in the wind. That's a fun tidbit that we gleaned from the instruction booklet, which is just as much a treat as it is building the model. It's packed full of fascinating facts about Discovery and the Hubble Space Telescope, adding to the building experience. The booklet's pages have a black background as the majority of the pieces are white, which makes the instructions stand out and easier to see. However, this does mean that fingerprints really show up on these pages, which will irritate perfectionists.

It's a satisfying build that will challenge you, but not to the point where you're tearing your hair out. It's one of the most beautiful and recognisable LEGO builds out there. You don't need to be a NASA superfan to know that this is one cool spaceship – every time you look at your completed LEGO NASA Space Shuttle Discovery, you'll be filled with a sense of pride... plus it makes a great talking point. It'll look good anywhere – once you find the perfect space for it, that is, as it's quite a sizable model!

The kit is finished off with stickers

You can display Hubble above the payload pay or on its own display stand

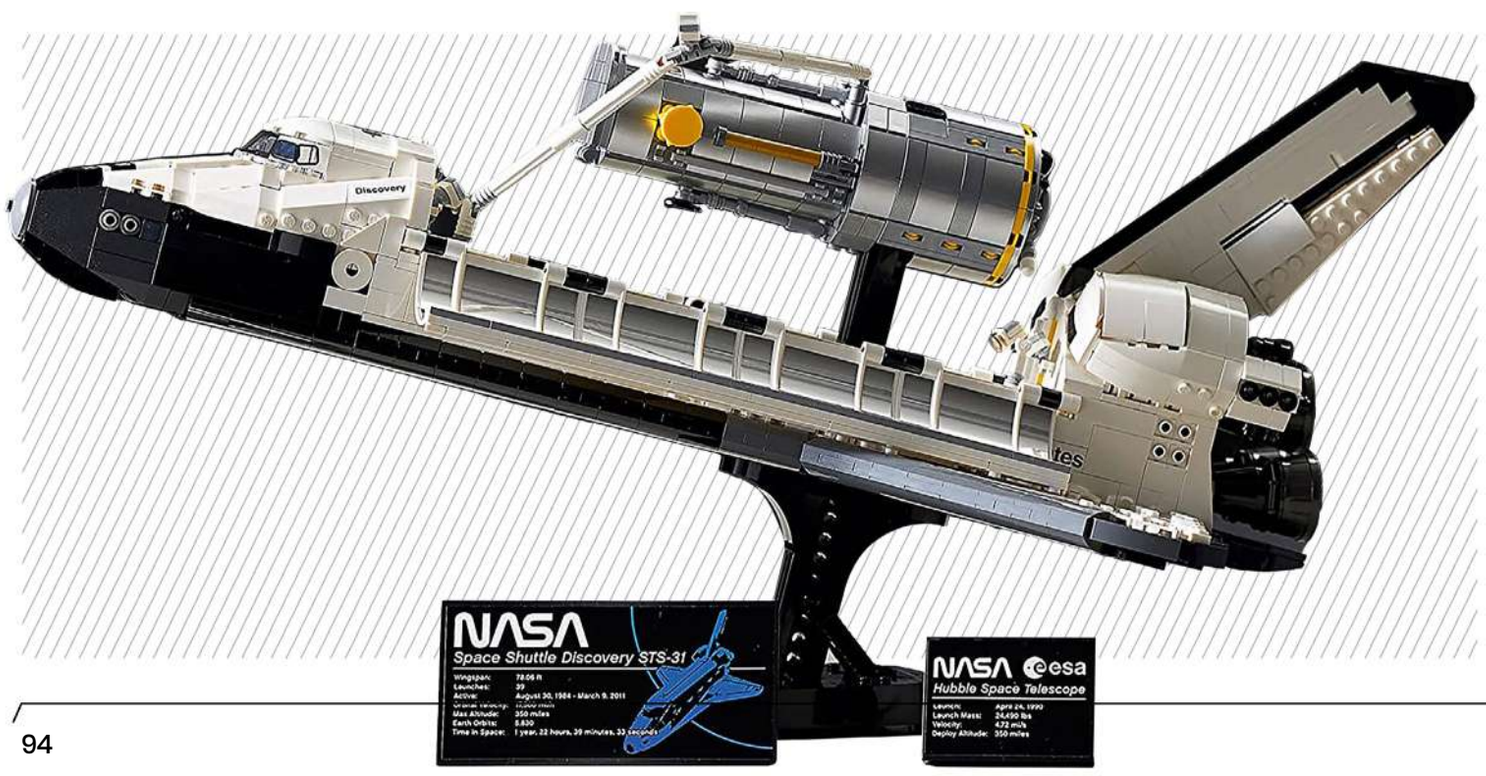
"It's a satisfying build that will challenge you"

FOR

- Two models in one kit
- Impressive replica
- An interesting and fun build

AGAINST

- No Minifigures
- Lots of shiny stickers can be a bit fiddly
- Metallic pieces scratch easily



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1

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3

For your home

Alien Abduction Lamp

Cost: £99 / $129
From: abductionlamp.com

1 This lamp seemingly hovers over your tabletop as the light beam underneath captures an unsuspecting cow, while little glow-in-the-dark aliens peer out. There are four different functions on the Alien Abduction Lamp: off; cockpit only, where the cockpit light pulses and phases through green and yellow lights; beam only, which features a steady glow from the bottom of the lamp, and all on, where the cockpit pulses and phases while the beam glows steady. The flying saucer is made of steel, with a black-pearl finish.

For everyone

Membership to the Society for Popular Astronomy

Cost: From £19 (approx. $24)
From: popastro.com

2 Getting to know the sky and stars is fun and educational. Membership includes a bimonthly copy of *Popular Astronomy*, where you can find observing guides and help with all aspects of stargazing, plus you can see what other members have been observing, all at a jargon-free level. Another benefit of membership is access to expert advisers who can help with a wide variety of topics. Popular Astronomy meetings are free of charge and can be viewed online, so you can join in wherever you live.

For skywatchers

Celestron StarSense Explorer DX 102AZ and StarSense Explorer LT 114AZ

Cost: £219 / $239.95 (LT) £379.99 / $429.93 (DX)
From: Celestron

3 Celestron has reinvented the manual telescope with StarSense Explorer – the first telescope that uses patented sky-recognition technology and your smartphone to analyse the night sky and calculate its position in real time. The StarSense Explorer range is ideal for beginners thanks to the app's user-friendly interface and detailed tutorials. It's like having a tour guide of the night sky.

4

"The aspheric lens works like a charm and eliminates any image distortion"

6

5

For casual skywatchers

Nikon Aculon A211 10x50 binocular

Cost: £99 / $119.95
From: Nikon

4 All of the usual binocular subjects can be picked out easily with these, from Jupiter's disc to the crescent Moon, with the optical system revealing crisp shadows at our natural satellite's terminator. The aspheric lens works like a charm and eliminates any image distortion. The rubber armour allows for a firm, shock-resistant grip that makes the binocular pleasing to hold. With a fairly large 6.5-degree field of view, this binocular is perfect for star clusters, planets and the Moon.

For game night

Star Wars: Outer Rim

Cost: £74.99 / $74.99
From: Fantasy Flight Games

5 For one to four players aged 14 and up, it's a thrilling contest of smugglers, mercenaries and bounty hunters all crafting their own personal legacies in the *Star Wars* universe. You'll get to play as some of your favourite scoundrels in this fun, fast-paced game. Mod your ship and build up your crew while you boost your reputation by completing bounties, delivering cargo and stealing supplies. But beware, you'll want to steer clear of warring factions and patrols. Intuitive to play and with so many different in-game encounters, you'll definitely want to make time for this one.

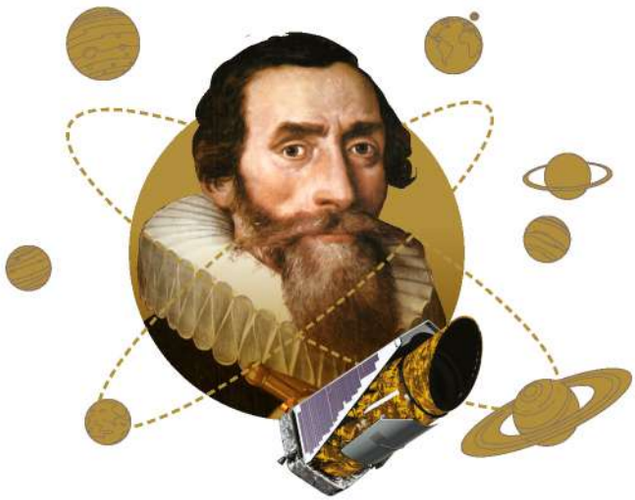
For dark-sky park seekers

MSR Hubba Hubba NX backpacking tent

Cost: £435 / $479.95
From: MSR

6 The MSR Hubba Hubba NX tent is a freestanding tent that's easy to put up. It can hold two people, so it's a good option if you're travelling alone or with a friend. The symmetrical geometry of this tent maximises the space as there's no central peak but an even shape all around. It's got a waterproofed rainfly cover, with the added benefit of StayDry doors, for any unpredicted heavy downpours. The rainfly cover can be rolled up, either partly or entirely, to uncover the tent's stargazer window.

HEROES OF SPACE



JOHANNES KEPLER

The astronomer who redefined our understanding of the Solar System

Kepler was born on 27 December 1571 in the small town of Weil der Stadt in what is now the German state of Baden-Württemberg. He became a proponent of the Copernican system of planetary motion in the early 1590s, and in 1596 he published *Mysterium Cosmographicum* (*The Cosmographic Mystery*), a detailed public defence of the theory, but it was a position that was still frowned upon. Kepler's laws of planetary motion wouldn't be formalised until after he began working with Danish astronomer Tycho Brahe in 1600.

Upon Brahe's death in 1601, Kepler was given access to the entirety of Brahe's observations of Mars, which allowed him to tackle the Martian conundrum that had been a thorn in the side of astronomers. The problem was that Mars appeared to move in a retrograde motion in the sky at certain times of year – it seemed to move backwards across the sky.

It would take Kepler several years to realise the reason for this was that the planets did not orbit the Sun in exactly circular orbits as Copernicus thought, but rather in slightly elongated ovals known as ellipses with the Sun not directly at the centre. This would become known as Kepler's First Law. This accounted for the Martian problem in that Earth would regularly 'catch up' to Mars in its orbit, making it seem to drift backwards across the night sky.

From his First Law Kepler derived a second, both of which he published in 1609. His Second Law surmised that as a planet travelled further from the Sun in its elliptical orbit, it slowed down, and vice versa. Thus for a given period of time a planet would sweep out the same area if an invisible line were drawn between the planet and the Sun.

His Third Law, published a decade later, correctly recognised the relationship between the time planets took to orbit the Sun and their distance. He asserted that the square of the ratio of the orbits of two planets was equal to the cube of the ratio of their radius, a complicated law to understand but one that was vital for explaining how the planets related to one another.

Kepler would go on to further expand upon his theories in addition to making other notable discoveries, such as that the Sun rotates, but his work was not widely accepted at the time. In fact, the latter years of his life were not wholly enjoyable; he was ostracised from several places for a variety of reasons and had to defend his mother against charges of witchcraft. He died in Regensburg, Germany, in November 1630.

ALL ABOUT SPACE ISSUE 132

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ALL ABOUT SPACE

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Printed by William Gibbons & Sons Limited, 26 Planetary Road, Willenhall, Wolverhampton, West Midlands, WV13 3XB

Distributed by Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU www.marketforce.co.uk Tel: 0203 787 9060

ISSN 2050-0548

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